A STUDY OF LATE QUATERNARY ENVIRONMENT AND MAN FROM FOUR SITES IN SOUTHEASTERN TASMANIA

BY

WAYNE RICHARD SIGLEO

A thesis submitted to the Faculty of Science in fulfillment
of the requirements for the degree of

Doctor of Philosophy

THE UNIVERSITY OF TASMANIA
DEPARTMENT OF GEOGRAPHY

1978

STATEMENT OF AUTHOR

Except as stated herein this thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief, this thesis contains no copy or paraphrase of material previously published or written by another person, except when due reference is made in the text.

Wayne Richard Sigleo

Wayne Richard Sigleo

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to my supervisor Dr. Eric A. Colhoun, for his inspiration, assistance and guidance throughout this study.

I am much indebted to Dr. Jamie Kirkpatrick of the Geography Department, The University of Tasmania, for providing most of the vegetation data from the lower Derwent Valley and the Midlands. I am also grateful to Messrs. Adrian Bowden, Albert Goede and Roger Kellaway of this department, and to Mr. Bob Wasson of Macquarie University for valuable discussions and assistance in the field. I wish to thank Dr. J.C. van Moort of the Geology Department of this university, and Dr. John Beattie of the Agricultural Science Faculty for assistance and advice in the pedological aspects of this study. I also thank Dr. Bob Jacklyn of the Physics Department for his inspiration and interest in Tasmanian archeology.

I wish to express my gratitude to several other people and institutions who provided assistance in many aspects of the study; Dr. Rhys Jones of the Department of Prehistory, The Australian National University; Mr. Peter Stephenson of the Tasmanian Mines Department; and the CSIRO Division of Soils in Hobart.

I gratefully acknowledge the technical assistance and support given by the Department of Geography; The University of Tasmania and all staff of the department. In particular, I wish to thank Mr. Guus van der Geer, Mrs. Kathryn Morris, Mr. Neil Chick and Miss Terese Flannagan.

I would like to express my appreciation to the Australian Department of Education for financial support throughout this research and the Australian Research Grants Commission for additional research funds.

Finally, but most important, I wish to thank my wife, Susan, who also endured the experience. Without her love, sacrifice and sense of humor this thesis would not have been possible.

ABSTRACT

A study of the geomorphic and stratigraphic relations of selected sandsheets, lunettes and associated landforms in southeastern Tasmania revealed a complex sequence of aeolian, slope and alluvial deposits including buried soils that were developed during the late Quaternary period. In addition, several of the aeolian deposits contained evidence of Aboriginal occupation, and provided information on the antiquity of Man in southeastern Tasmania and his role in locally modifying the landscape.

At least two major phases of aeolian activity are recorded from the late Quaternary period, each related to relatively cold, and seasonally arid conditions that occurred during and/or immediately following episodes of periglacial activity in the lowlands of Tasmania. The age of the initial phase of deflation is yet to be determined; however, aeolian activity could have occurred during either the Penultimate Glaciation or an early stadial of the Last Glacial Stage. The aeolian sediments of this phase unconformably overlie still older alluvial fan and lacustrine deposits. These were formed during cold climatic conditions when geomorphic processes causing slope instability and alluviation of small catchments operated with greater intensity than during warmer and moister intervals. Reduced precipitation was more than counter-balanced by reduced evaporation to maintain high lake levels in the Midlands. Truncated paleosols on the older sandsheets and dunes indicate that a period of climatic warming of unknown duration and intensity occurred between the two major colder and drier episodes.

Renewed deflation, resulting in the accumulation of younger sandsheets and lunettes, occurred during the later part of the Last

Glacial Stage, and was broadly synchronous with a second period of fan deposition and high lake levels. An approximate age for this phase of aeolian activity is indicated by a radiocarbon date of 15,740 BP from a sand dune at Malcolms Hut. Pollen evidence from lake sediments in the Midlands suggests a considerably colder climate throughout much of this period. Archeological material from the base of a sandsheet in the lower Derwent Valley demonstrates the presence of Aboriginal Man in southeastern Tasmania by at least the later part of the Last Glacial Stage. Towards the end of the Last Glacial Stage, increased summer temperatures and evaporation rates resulted in intermittent or seasonal drying of the lake basins in the Midlands and clay dune formation.

This later phase of aeolian activity was followed by soil development on the various sandsheets and lunettes, and weathering occurred during the general climatic amelioration beginning at the end of the Last Glacial Stage. Relative land surface stability continued during the Holocene until profile truncation occurred locally through Aboriginal occupation, and the site-intensive activities of Man were responsible for the generation of secondary, anthropogenic coversand deposits at some of the sites. Radiocarbon dates indicate the profile truncation caused by Aboriginal occupation occurred by at least 5,800 BP in the lower Derwent Valley and by 4,800 BP in the Midlands. European land use and quarrying activities after 1803 resulted in the disturbance of the Aboriginal occupation units and initiated the deposition of tertiary aeolian deposits.

A reasonable framework exists for correlation of the major late Quaternary events in southeastern Tasmania presented in this study with similar sequences recorded from adjacent parts of the Australian mainland.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

Part I

INTRODUCTION, METHODS AND DESCRIPTION OF THE STUDY AREAS

CHAPTER 1

INTRODUCTION

Most previous Quaternary research in Tasmania has been conducted in the glaciated highlands and associated periglacial areas. In contrast, there are few studies from the nonglaciated lowlands, and these have been primarily concerned with coastal landforms, isolated alluvial sequences and the paleoclimatic significance of inland aeolian sandsheets and lunette dunes (Davies, 1967).

Inland dunes are widely distributed throughout southeastern Tasmania and are usually found on the eastern sides of major rivers and small lakes. Such dunes have been cited as evidence for past aridity, but divergent theories have been forwarded as to their actual environmental significance and age of formation. Many dunes contain evidence of Aboriginal occupation (Jones, 1968) and a study of their stratigraphy should provide information concerning the relationship between the Aboriginal and his environment.

Aims - The purpose of this dissertation is to investigate the origins of selected inland dunes and associated deposits in southeastern Tasmania, and to evaluate their paleoenvironmental significance. Where archeological evidence is available, the individual deposits are considered in the context of their cultural significance and the antiquity of Man in Tasmania.

The aims are basically threefold: 1) to identify periods of climatic change which may have favored regional aeolian activity; 2) to provide an understanding of the physical environment as an ecological setting to human prehistory; and 3) to establish a tentative model of late Quaternary environmental change for southeastern Tasmania, from which comparisons may be made with other Australian research.

The basic approach is interdisciplinary, and incorporates stratigraphic, palynologic and soil-stratigraphic techniques to support the overall geomorphic framework.

Four principal dunes were selected for detailed analysis. These include source-bordering sandsheets at Glenfield, Old Beach and Bridgewater in the lower Derwent Valley, and a small lunette at Crown Lagoon in the Midlands (Fig. 1). These sites were chosen because the dunes are composite stratigraphic features which contain evidence of Aboriginal occupation. Several other sandsheets and lunettes were also investigated in less detail to provide a basis of regional comparison and correlation.

Structure - The study is in four parts. The introduction contains the aims and reviews previous research from southeastern Australia and Tasmania which is relevant to the study; the research methods; and a description of the study areas. Part II is a geomorphic and stratigraphic evaluation of the principal sites in the lower Derwent Valley, and in less detail, that of several others from the adjacent area.

The third part considers the evidence from two lunettes in the Midlands along with a discussion of their environmental significance. Part IV, entitled the Paleogeographic Environment, is a synthesis and correlation of the evidence from the lower Derwent Valley and Midlands sites. This part also contains a tentative correlation of the results of this study with that of the previous Australian research. The final chapter summarizes the conclusions and contains brief recommendations for future research.

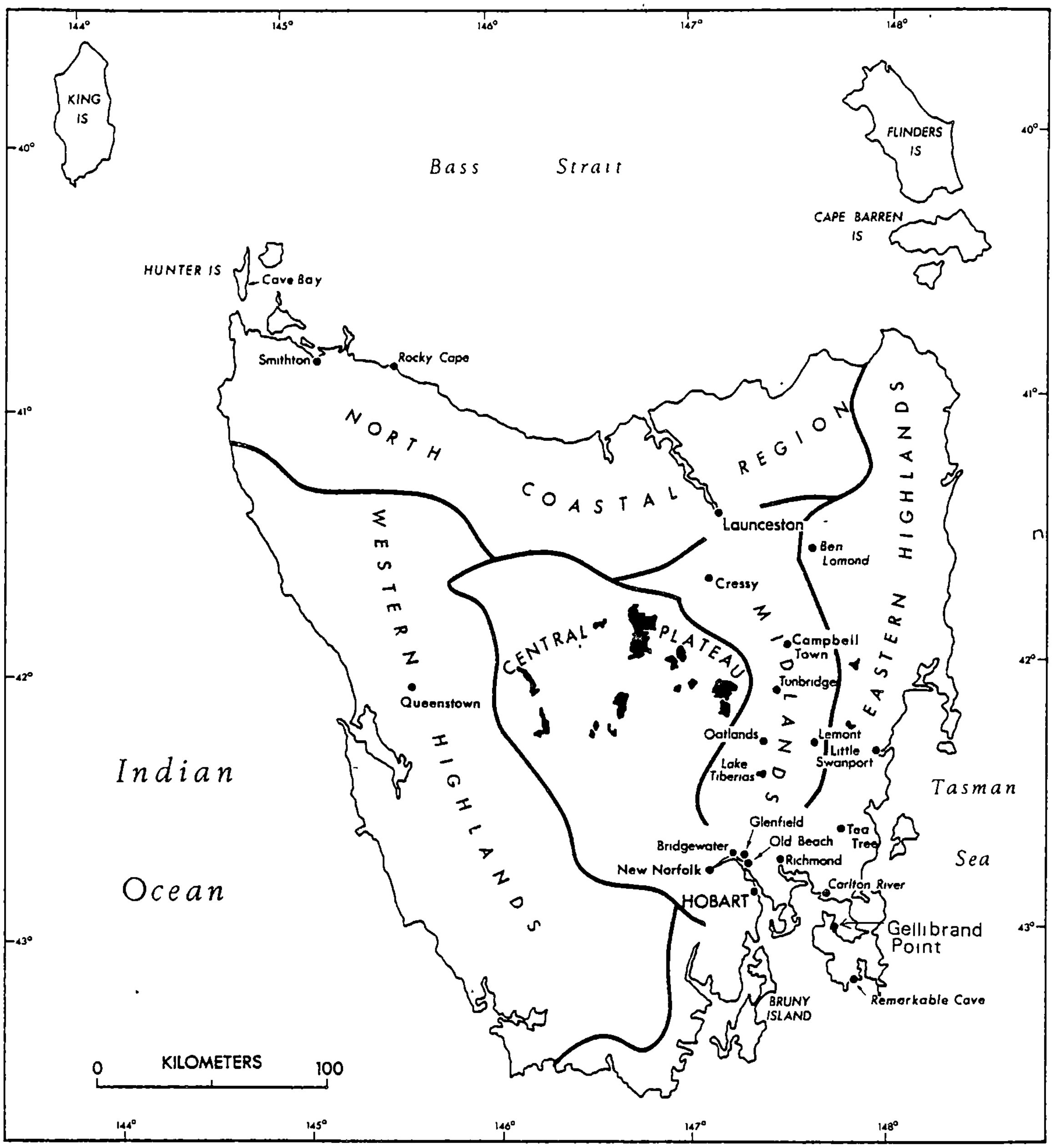


Figure 1. Location Map of Tasmania

PREVIOUS QUATERNARY RESEARCH

Southeastern Australia

Geomorphology - The nature of late Quaternary environments in Australia is a subject of controversial debate, and relative to the established sequences of the Northern Hemisphere, paleoenvironmental reconstructions for Australia are largely incomplete. This situation is primarily due to the relatively recent interest in such research and to the difficulties in establishing absolute chronologies from many areas of the continent.

An early hypothesis of late Quaternary environment in Australia considered that relatively warm, pluvial conditions existed over much of the continent during the last glaciation (Browne, 1945; Crocker and Wood, 1947; Gentilli, 1961). The evidence was based on the large number of extinct river systems and playa lakes in the now arid interior, and on analogs borrowed from the Northern Hemisphere. Browne (1945) stated that "... the Pleistocene Period was a time of high rainfall and the continent ... was a land of brimming rivers, spreading swamps, and full-bosomed lakes...". Fossil evidence of extinct megafauna and temperate plants was also cited to support the hypothesis of former pluvial conditions in the interior.

Deglaciation of the Southern Highlands was thought to have been accompanied by desiccation in the lowlands with rising temperatures beginning around 10,000 years ago. Browne indicated that the most spectacular evidence for an almost continental shift from pluvial to arid conditions was the vast expanse of sand ridge deserts in the interior. Browne (1945) and Crocker and Wood (1947) thought that the deserts were the result of a single and dramatically rapid climatic shift to aridity. The change from glacio-pluvial conditions to an arid phase was explained by a northward shift of the tropical rain belt and an expansion of the subtropical anticyclone zone in the continental interior (Gentilli, 1961).

Views on the age of the supposed Holocene[1] aridity varied considerably. Crocker (1946) indicated that the extent of maximum aridity occurred less than 9,000 years ago. Gill (1955), on the basis of a single radiocarbon date on shell at Lake Colungulac, suggested that a thermal maximum occurred about 5,000 years ago. Gill considered that the thermal maximum was synchronous with the "Climatic Optimum" in Europe (Flint, 1947) and the "Altíthermal" in North America (Antevs, 1948). The major effect of aridity was thought to be the catastrophic destruction of vegetation leading to accelerated wind and water erosion (Crocker, 1946). The extinction of the Australian megafauna was cited as a corollary line of reasoning supporting the concept of the thermal maximum (Browne, 1945). However, Merrilees (1967), following theories advanced by Martin (1966), suggested that Aboriginal predation and habitat burning was largely responsible for the extinction of many of the large marsupials.

Later investigations have been primarily concerned with the identification of either arid or pluvial conditions with the Last Glacial Stage. Galloway (1965a, b; 1967) presented evidence against the widely accepted glacio-pluvial concept, and suggested that during the last glaciation southeastern Australia was cold, windy and dry. He deduced paleotemperature data from the present and past limits of solifluction[2] and snowlines

---

[1]The Holocene-Pleistocene boundary has not been determined in Australia. For the present purposes, the lower Holocene boundary of 10,000 radiocarbon years BP, recommended by the Holocene Commission of INQUA, 1969, is used in this dissertation.

[2]Unless otherwise stated, the term "solifluction" in this study is taken to mean mass wasting of rock fragments or soil resulting from frost activity and gravity flowage. The term implies strong winter frost conditions, but not permafrost. (Butzer, 1964; Washburn, 1973).

from the Snowy Mountains of New South Wales, and suggested that the mean annual temperature was some 9° C lower. This value is of similar magnitude to that derived from North Island of New Zealand for the last glaciation from preliminary speleothem data (Hendy, 1969).

Galloway identified abandoned shorelines at 30 m and 13 m above the floor of Lake George in New South Wales, and ascribed the "pluvial" character of the lake to a more effective precipitation regime through lower temperatures and evaporation during the last glaciation. He suggested that, while total precipitation decreased, annual spring floods created runoff equal to or exceeding the present. Galloway indicated that the lake had not overflowed since before the maximum of the last glaciation, and described a strongly differentiated podzolic soil on colluvium blocking the overflow, and a less well developed soil on the 13 m shoreline. He obtained a radiocarbon date of 15,000 ± 300 BP (GaK-962) from the 13 m shoreline which agrees reasonably well with cold, but ameliorating conditions in the Snowy Mountains as suggested by Costin (1971).

Two generations of possible periglacial slope deposits and alluvial fans were reported around the margins of the lake, although their time-stratigraphic position is not identified. However, these deposits had soils thought to be similar to those formed on the high shoreline features and Galloway suggested that the fans were apparently deposited during low lake levels during the last glaciation. He did, however, indicate that only a short time interval may have separated the periods of slope instability from the times of high lake levels.

Conversely, Dury (1960; 1967; 1968) argued that late Pleistocene climates in Australia were pluvial in nature. Using the calculated discharges for "underfit" streams in Australia, Dury suggested that the disparity between present and former river flows could only be explained by an increase in annual precipitation during the last glaciation. He states (1960, p. 235) that "... an increase in mean annual precipitation by a factor of 1.5 to 2 is needed, in addition to a reduction in temperature, to supply the former discharges of streams which are now underfit." Dury cited evidence supporting the glacio-pluvial relationship from North America (Morrison, 1965) and suggested that similar conditions occurred in Australia at roughly the same time.

Geomorphological and pedological studies from the Riverine Plain, western New South Wales have provided contradictory statements concerning the nature of the late Pleistocene climates of southeastern Australia. In a study of the stratigraphic history of prior stream channels, Butler (1950, 1958) concluded that the older fluvial sediments were deposited during a more arid climate than present. This interpretation was based on the close association between aeolian parna sheets and prior stream deposits. Butler suggested that the parna indicated relatively arid conditions to the west of the Riverine area during the periods of prior stream aggradation.

Butler argued that the mechanism controlling prior stream deposition was a high ratio of load to discharge in the highland catchment areas. He suggested that with reduced precipitation there would be a reduction in vegetation with increased erosion in the catchments. Nondepositional phases were thought to be associated with channel incision and soil formation during more humid climatic conditions (Butler, 1959).

Langford-Smith (1959; 1960; 1962) argued the opposite viewpoint and supported Dury's hypothesis of glacio-pluvial environments. He indicated that the major phases of sedimentation occurred during pluvial conditions which were contemporaneous with full glacial conditions in the highlands. Commenting on the great length of the prior stream channels and their wide meander belts, he states (1959, p. 74) "... it is difficult to reconcile arid conditions with the enormous discharges indicated by the prior stream distributary systems...". Langford-Smith also suggested that the main phases of sedimentation were the result of annual spring meltwater during late glacial times. He (1962) later modified the glacio-pluvial origin somewhat, and indicated that while the coarser grained alluvial deposits were associated with channel braiding in the glacial period, the finer sediments were deposited during the waning pluvial stage at the end of the last glaciation (Cotton, 1963).

More detailed geomorphic investigations in the Riverine area by Schumm (1968) tend to support Butler's theory of arid conditions during the last glaciation. Evidence favoring this hypothesis is given by Pels (1971) who presents numerous late Pleistocene radiocarbon dates for the older aggradation phases. However, the Riverine problem is far from being resolved and additional research, especially pollen stratigraphic evidence, is needed to clarify the paleoenvironmental correlations.

Lunettes and their associated lake basins provide another key to understanding the patterns of late Pleistocene climatic changes in Australia. The dunes are found in many semiarid regions of the world, but they are comparably more abundant in Australia. Lunettes were first described by Hills (1939; 1940) who concluded that the dunes formed on the lee sides of full lakes by spray capture of atmospheric dust particles. Stephens and Crocker (1946) considered this theory to be somewhat inadequate and suggested that lunettes were the accumulation of wind-transported, pelletal material blown from the exposed lake floors during periods of aridity. These authors concluded that the wide textural variability of the lunettes was dependent on the source and availability of the parent material deposited in the lake basin. More recent research on lunettes by Bettenay (1962) and Campbell (1968) support the aridity hypothesis, but Curry (1964) suggested that some lunettes were formed by the deflation of beach material during oscillating lake levels.

Lunettes have been used to support the hypothesis of a "Great Australian Drought" during the post glacial period (Gill, 1955). However, Bowler and Harford (1966) suggested that certain types of lunette sands could only be derived by the deflation of sandy beach material during high lake stages.

In a study of the Willandra River system in New South Wales, Bowler (1971) found a sequence of alternating aeolian sand and clay units in lunettes bordering the eastern margins of several hydrologically related lakes. Bowler identified three major soil-stratigraphic units in the lunettes; the basal Golgol, the intermediate Mungo, and the most recent Zanci. Each consisted of a basal siliceous sand unit overlain by a weathered clay deposit. From detailed radiocarbon evidence, Bowler (1973b) suggested that the lunette sediments record two late Quaternary, high lake stages, including the Mungo (40,000-25,000 BP) and the first part of the Zanci high lake stage (23,000-17,000 BP), separated by a minor drying phase, the Mungo oscillation (25,000-23,000 BP). The older Golgol unit lies outside the range of radiocarbon dating and is related to an earlier high stage of indeterminate age.

The lunette sands were associated with high lake stands and were thought to have been derived by the deflation of beach sands. Bowler related the high lake stages to cooler temperatures, high runoff and low evaporation rates, but he did not speculate on the regional climatic implications. Radiocarbon dates (Bowler, 1968) on sand lunettes at Lake Echuca, Victoria (20,000-13,000 BP) and Lake Menindee, New South Wales (26,000-18,000 BP) provide additional evidence to support the Zanci high lake stand during the later part of the Last Glacial Stage. Bowler and Hamada (1971) also reported a high lake stand in Lake Keilambete, Victoria from 30,000 to 18,000 BP. In contrast, Dury (1973) reported high lake stands in northern New South Wales prior to 15,000 BP, but suggested that these resulted from a higher precipitation regime rather than from reduced evaporation.

The clay units in the lunettes were thought by Bowler to have resulted from the deflation of clay aggregates from drying lake floors during subsequent periods of rising temperatures and increased evaporation rates. Bowler's sequence records two periods of lake drying and clay dune formation, the last of which occurred after 17,000 BP. He suggested that this phase marked the beginning of a major period of aridity and aeolian activity in Australia. He related this to a combination of high summer temperatures and cold, dry winters. These conditions would favor a high frost incidence and soil moisture deficit that would limit plant growth and favor the formation of clay dunes.

A maximum date of 13,725 BP on a clay dune at Lake Colungulac, Victoria (Gill, 1955) provides additional support for desiccation during the final phase of the Last Glacial Stage. Bowler and Hamada (1971) have also reported that Lake Keilambete was dry between 15,000 and 10,000 BP, further supporting late glacial aridity. In addition,Bowler (1967) dated three periods of source-bordering dunes formed between 25,000 and 8,000 BP in the Goulburn Valley, Victoria and suggested that deflation occurred during periods of high stream discharge.

The above data strongly suggest that the Last Glacial maximum was characterized by cooler temperatures with much reduced evaporation rates, at least in southeastern Australia. There is no conclusive evidence to support pluvial conditions with increased precipitation and the regional climate may have been more arid. The age discrepancy between Galloway's high lake stand at Lake George and Bowler's Zanci high lake stage may be related to the inherent climatic differences between the two areas. In this respect the late glacial climatic amelioration in the lowlands probably began sooner than in the highlands and seems likely to have been characterized by higher summer temperatures and increased evaporation rates.

Pollen Studies - Limited palynological data from southeastern and southern Australia provide strong supporting evidence for late glacial arid conditions. Dodson's (1975) pollen study of lake sediments from Lake Leake, South Australia has indicated that climatic conditions were relatively dry from about 50,000 to 39,000 BP and from after 38,000 until about 10,000 BP. Superimposed on this general trend towards aridity are relatively wetter periods of short duration at ca. 50,000 and 39,000 BP and from about 38,000 to 35,000 BP. Martin (1973), in a study of cave sediments in the Nullarbor Plain, has also indicated that between 20,000 and 15,000 BP, the climate was as arid as today and at no time did the vegetation cover approach that of the present.

It is significant to note that both Martin and Dodson (1974) have recorded a relatively wet period during the mid-Holocene, supporting

Churchill's (1968) pollen data from western Australia. Martin has also suggested that a local reduction in vegetation during the mid-Holocene resulted from Aboriginal burning and vegetation clearing.

Prehistory - Over the past ten years archeological research has produced a wealth of information concerning the antiquity and culture of Man in Australasia (Golson, 1972; Jones, 1973). The earliest published date of Man comes from the Lake Mungo lunette in western New South Wales where unionid shells believed to be contemporaneous with human occupation have been dated to 32,750 ± 1,250 BP (ANU-331) (Bowler, et al., 1970). This material, found in a sand unit of the lunette, was deposited during the Mungo high lake stage. A human cremation, also contained in the deposit, was dated to 25,550 ± 1,000 BP (ANU-618b) (Jones, 1973). The female skeleton was fully sapient and her characteristics were within the morphological range of modern Australoids (Thorne, 1971b).

Other dated lunette sites in New South Wales with evidence of human occupation include Lake Menindee, 26,300 ± 1,500 BP (LJ-204); Lake Victoria, 18,200 ± 800 BP (GaK-2514); and Lake Yantara, 26,200 ± 1,100 BP (GaK-2121) (Jones, 1973; Mulvaney, 1968).

Another old site is found at Keilor, southern Victoria where evidence of probable human occupation has been dated to 31,600 $^{+1,100}_{-1,300}$ BP (ANU-65) (Mulvaney, 1968), but there is disagreement as to whether or not all the stone material is humanly produced (Gallus, 1971). Other evidence of human occupation in Victoria include dates of 17,720 ± 840 BP (ANU-840) from Cloggs Cave and 18,000 ± 500 BP (Nz-207) from a higher stratum at Keilor (Jones, 1973).

One of the most interesting sites is Kow Swamp in Victoria where human skeletal material with certain morphological features similar to *Homo erectus* has been dated between 8,000 to 10,000 BP (Thorne, 1971b; Thorne and Macumber, 1972). Thorne postulated that two populations may have been present in Australia, and suggested that an older, archaic one could have been replaced or added to by an essentially modern one sometime after 25,000 BP.

The preliminary archeological evidence suggests that Man migrated from some part of southeast Asia when sealevels were lower during the last glaciation. If environmental conditions were suitable for rapid migration, the continent may have been occupied by Man in a relatively short period (Birdsell, 1957). Jones (1973) has suggested that the theme of Australian prehistory was one of vast cultural continuities in both time and space, and that a broadly based, foraging economy was established by at least 20,000 BP with little or no change in this pattern until European occupation of the continent.

Tasmania

Geomorphology - As with the Australian continent, much of the previous Quaternary research in Tasmania is fragmentary and highly generalized. Many studies are limited to an explanation of locally occuring geomorphic phenomena, and until very recently, little or no attempt had been made to place the systematic evidence into a broader, regional framework.

As stated earlier, the bulk of previous research has been conducted in the glaciated highlands and associated periglacial areas of the island (see Davies, 1967; Derbyshire, 1972). Since these studies are peripheral to the central emphasis of this dissertation, only brief mention will be given here to the glacial history of the island.

During the upper Pleistocene, an icecap covered most of the Central Plateau and spread south, north and west along major river valleys. Cirque and smaller icecap glaciers were present in the Western Highlands and also in the higher valleys of other parts of the island. A radiocarbon date of 26,480 ± 800 BP (W-323) from the Linda Moraine near Queenstown has been widely quoted as the maximum date for the last major ice advance in western Tasmania (Ahmad et. al., 1959; Gill, 1956).

During glaciation the regional snowline occurred at about 600 m in the west and valley glaciers descended to terminal moraines which occur within 60 m of sealevel. The regional snowline extended to about 1,350 m on the Ben Lomond plateau in the northeast where the ice did not reach below 900 m. The lower limit of periglacial solifluction is somewhat difficult to determine, but previous estimates range from 300 to 600 m (Banks, 1965; Davies, 1967; Spry and Banks, 1962).

The origins and environmental significance of the inland sand-sheets and lunettes of central and northeastern Tasmania have been discussed by Nicolls (1958b, 1960) and Davies (1967, 1974). Brief reference is also made to individual lunettes in northern Tasmania by Stephens et. al., (1942) and Stephens and Crocker (1946), but these accounts do not consider the dunes in a geomorphic context.

Nicolls (1958b) recognized that the sandsheets were derived by the deflation of sandy alluvium from adjacent floodplains under the influence of westerly winds. The dunes were recorded as being particularly common in the Launceston Basin, along the Derwent River between Ouse and Bridgewater, and along the Jordan, Coal and other rivers of southeastern

Tasmania. Nicolls noted that the sandsheets varied in thickness from a few centimeters to several meters, and in area from a few square meters to about eight square kilometers.

The dunes were reported to blanket the landscape and to overlie all river terraces and other formations except the most recent alluvium. Nicolls described the sediments as consisting mainly of quartz sand with plagioclase feldspar and weathered accessory minerals. Some dunes were reported to contain significant amounts of clay and these were thought to have originated by the deflation of clay aggregates in a manner similar to the formation of "dune parna" on the mainland (Butler, 1956). Nicolls indicated that some of the sheets were being actively eroded under local agricultural mismanagement, but that most were stabilized by vegetation. He states (p. 50) that "... accumulation may therefore be ascribed to past environmental factors, now operative at a much lower intensity, if at all."

Nicolls felt that the sandsheets implied periods of severe stream flooding, alternating with periods when the alluvial deposits were dry enough to be eroded by the wind. He indicated that this type of fluvial regime would be consistent with either a warm, semiarid environment or with periglacial conditions in which floods followed spring thaws. Nicolls suggested that the sandsheets were one of the effects of the last glaciation in Tasmania and argued that the deflation was associated with a periglacial environment. The widespread distribution of solifluction deposits in the highlands was cited as indirect evidence for periglacial river regimes in the lowlands and the sandsheets were considered to be similar to the loess-type deposits of New Zealand and the Northern Hemisphere.

Nicolls ruled out an origin due to warm, semiarid conditions during the Holocene and presented evidence from the Launceston Basin contrary to this hypothesis. Here many of the low interfluves have lateritic soils with sandy A horizons, and Nicolls reasoned that, as the interfluves would be the driest part of the landscape during an arid period, the effects of vegetation reduction would not permit preservation of the A horizons. He states (p. 50) "... the only evidence of sand movement on the interfluves is the accumulation of relatively small lunettes on the leeward side of lagoons.", and that "... the absence of large-scale sand movement on the interfluves may in fact be taken to indicate that during the Recent Arid period aridity in this area was not particularly severe."

Nicolls (1958a) mapped the soils developed on the sandsheets in the Launceston Basin as the Panshanger Association and described them as generally yellowish brown, immature profiles. Locally some of the soils were reported to be grey and more leached. The surface texture was described as loamy sand with in some cases a clayey sand subsurface horizon. He suggested that the brown color of the sands was due to iron coating of the grains and need not be taken as evidence of aridity.

Davies (1967, 1974) reviewed the problem of the inland dunes and divided them into three categories; sandsheets on the eastern sides of river valleys; lunettes on the eastern sides of small lakes or depressions; and sandsheets derived by the deflation of the A horizons of podzolic soils developed on Triassic sandstone. Davies indicated that, with few exceptions, the inland dunes were restricted to the subhumid (<750 mm precipitation) region of Tasmania, and he thought that these landforms were associated with periods of aeolian activity and stream aggradation when channel braiding was prevalent.

Davies suggested that saltation of sand over considerable distances from the floodplains required some reduction in the vegetation cover. He doubted a periglacial origin for the sands in most cases and states that the present distribution of the sandsheets "... supports an origin due to excessive drought rather than excessive cold...", and thus implied that the dunes were probably formed under semiarid conditions. However, he cautiously indicates that "If the sandsheets at Bridgewater on the Derwent are in fact wind-redistributed alluvium, this ... would support a Pleistocene (low sealevel) age, since they border a section of the river now drowned by the sea." Davies concluded that the question of the sandsheets "... remains an open one and the real relationship may prove complex." (1967, p. 23)

Davies concluded that the lunettes were formed in a warm, semiarid environment. This conclusion was based on Stephens and Crocker's (1946) theory that the dunes were derived by deflation from dry lake floors during periods of aridity. Davies states (p. 23) "... rarely does a climate such as the present allow the floors of the associated depressions to dry out sufficiently for wind action to take effect, and the dunes show no evidence of recent accretion." He indicated that lunette formation seemed to have occurred during a mid-Holocene arid period, and based this conclusion on two radiocarbon dates of 4,170 ± 80 BP (ANU-279) and 4,860 ± 95 BP (ANU-278) from Aboriginal horizons in the lunette sands at Crown Lagoon. He further suggested that the soil profile development in some of the sandsheets was similar to that on the lunettes, and thus implied that many of the sandsheets were formed during the mid-Holocene. However, Davies has concluded in a more recent article (1974, pp. 23-4) that it would be wrong "... to assume that all fossil dunes in Tasmania are of this general age but it is a fair presumption from their relative soil profile development and geomorphic relationships that at least a large proportion of the inland dunes may be so assigned."

These earlier studies demonstrate that there is considerable disagreement as to the exact nature and environmental significance of the various inland dunes. The most important difference lies in the origin of the sandsheets and their association with either a warm, semiarid climate or with periglacial conditions. In this respect, neither author can refute the other's interpretation in terms of their own evidence. Nicolls cited indirect evidence of a periglacial origin from the distribution of solifluction deposits in the highlands, but did not provide evidence from the lowlands to support his hypothesis, other than the sandsheets. Davies suggested that some of the sandsheets may be Pleistocene in age, but does not provide an interpretation of the depositional environment, which is clearly critical to Nicolls' argument.

Davies, and Nicolls to some extent, supported a mid-Holocene arid period in Tasmania, but their interpretation is based on incomplete evidence that is not controlled by radiocarbon dating. Nicolls used the presence of sandy A horizons of soils on the low interfluves to question the severity of the aridity, but he did not consider the possibility that these horizons were wind-transported deposits distinct from the lateritic soil profiles. Davies partially suggested a mid-Holocene arid period from limited radiocarbon control in a single lunette, and with this evidence attempted to explain the origin of a large proportion of the inland dunes.

He indicated that the degree of soil development on the lunettes was similar to profiles formed on the sandsheets, but did not present detailed stratigraphic and pedologic information to support this conclusion. Davies also used dated evidence of a mid-Holocene aggradation phase from fluvial sequences in southeastern Tasmania (Goede, 1965, 1973) to support his argument of aridity, although Goede suggested several other possibilities including Aboriginal burning as a cause of accelerated catchment erosion.

Pollen Studies - There are no detailed pollen stratigraphic studies published from Tasmanian Quaternary sequences, but brief reference is made to isolated pollen examinations from several localities. Duigan (Paterson et. al., 1968) analyzed undated glaciolacustrine sediments from Lemonthyme Creek in the Forth Valley, and found the most frequent pollen type to be *Nothofagus*, including the *brassi* group which no longer occurs in Australia. The samples also contained the coniferous pollen *Microcachrydites antarcticus* and *Dacrydium mawsonii*. Duigan suggested that the pollen could be either Pleistocene in age or reworked from Tertiary deposits.

Ingle (Jennings, 1959b) analyzed a sample from a deltaic deposit at City of Melbourne Bay on King Island. Wood from the deposit was dated to 37,500 $\pm$ 1,900 BP (R-345), and Ingle found the following pollen percentages:

Phyllocladus aspleniifolius	91.5%
Drimys lanceolata	4.5
Nothofagus cunninghamii	1.0
Myrtaceae	0.5
Unknowns	2.5

Numerous spores were found including *Dicksonia (?)*, *Cyathea* and *Polypodium*.

Cookson (Gill and Banks, 1956) analyzed several samples from the Mowbray Swamp near Smithton. One sample was obtained from peat near the locality which yielded the holotype of *Nothotherium tasmanicum*, an extinct giant marsupial. Marl and peat from the deposit was dated at >37,760 BP (Y-148-1; Y-148-2) (Barendsen et. al., 1957) and Cookson reported: *Eucalyptus*, Gramineae, Compositae and other unidentified pollen. She noted *Banksia*, *Gunnera*, *Haloragis*, *Hypolaena*, Compositae, Chenopodiaceae and Gramineae from an undated peat sample in another area of the swamp which was also associated with the bones of extinct marsupials. In addition, a carbonaceous sand deposit from an adjacent inland dune yielded Myrtaceae, *Podocarpus alpina* (?), Compositae and Gramineae. Gill and Banks suggested that these various pollen samples indicated an open forest environment and that the extinct marsupials had inhabited open glades near the swamp.

Litchfield (Goede, 1973) analyzed several samples from the Brockley II alluvial sediments dated to 4,435 ± 110 BP in the Tea Tree Rivulet of eastern Tasmania. The relative frequencies are not given, but Litchfield reported high percentages of Myrtaceae pollen while Gramineae and other herbaceous pollen was relatively low. The pollen of Myrtaceae was not differentiated, although Goede suggested that woody Myrtaceous species grew on the floodplain during the period of alluvial deposition. He suggested that this community was similar to the dense tea tree scrub *(Leptospermun spp.)* which grows on the modern floodplain, except in cleared areas. The interpretation of densely vegetated floodplain is curious as both Goede and Davies have used the Brockley II aggradation phase as evidence to support a mid-Holocene arid period.

Prehistory - In contrast to the wealth of information from the mainland, the Tasmanian record is relatively incomplete (Jones, 1973; Mulvaney, 1968). Archeological sites are numerous and widely distributed in Tasmania, but few have been investigated in detail and serious research has only been conducted in the last 5-10 years. Modern ethnographic evidence on the Tasmanian culture is not available as the Aboriginals became extinct in 1876 through contact with European settlers (Jones, 1971). Some historical information is available (Hiatt, 1968), but this source has been criticized, as many of the conclusions are based on indirect observations made sometime after European contact (Lourandos, 1970).

The known distribution of archeological sites indicates that Aboriginals occupied most of the island except for the rainforests of the west (Jones, 1968). Jones suggested that the inhospitable rainforest environment lacked the available animal food resources to sustain permanent occupation. Some ethnographic evidence exists for Aboriginal penetration of the rainforest (Hiatt, 1968), but there is no evidence to support the existence of occupation sites.

Hiatt suggested that the Tasmanian economy was based primarily on terrestrial hunting and gathering with coastal shell fishing and gathering. The Tasmanians lacked the dog as a hunting aid until after European contact. They hunted in family groups and used animal drives to ambush or trap game. The economy in coastal areas was based predominantly on shell fishing, plant and egg gathering, and locally on seal and bird hunting. There is evidence to indicate seasonal migration from the coast to inland areas due possibly to a limited supply of coastal food resources (Hiatt, 1968; Lourandos, 1970).

The Tasmanian material culture apparently lacked the spear-thrower, boomerang, shield, axe and adze; typical tools of mainland Australian assemblages. The Tasmanian used simple wooden spears and clubs and lacked composite hafted tools. Their stone implements consisted mainly of hand-grasped scrapers produced as flakes from pebbles and some flakes show shaping and retouching. Of the mainland typological collections the Tasmanian material culture resembles that of the Kenniff Cave assemblage in New South Wales dated to 16,130 ± 140 BP (NPL-68) (Mulvaney, 1968).

Archeological investigations in Tasmania are limited to sites of which only a few have been considered in their geomorphic context. The oldest dated site is located at Cave Bay Cave on Hunter Island off the northwest coast and is dated to 18,550 ± 600 BP (ANU-1361) (Bowdler, 1974a,b). The date, obtained from a thin cultural horizon between 80 to 100 cm from the surface, is associated with the bones of small marsupials, a bone point and two pieces of flaked quartz. From her preliminary evidence Bowdler indicated that the cave was a sheltered occupation site on the Bass Strait plain exposed by the glacio-eustatic lowering of sealevel.

Jones (1966, 1968) excavated several sites on the northwest coast of Tasmania. The oldest of these is South Cave at Rocky Cape, dated at 8,120 ± 165 BP (GxO-266) (Reber, 1965). This deposit is a shell midden within the cave and contains evidence for two distinct phases of Aboriginal occupation. The older, associated with large quantities of fish and seal remains, probably indicates an almost complete dependence by the Aboriginals on the sea as a source of protein. The younger occupation phase, beginning around 6,000 BP, contains more terrestrial mammal and avifaunal remains, and suggests a shift toward a more mixed Aboriginal economy. However, the stone artifacts found in each phase are essentially similar and consist of crudely retouched flakes and flaked pebbles.

A date of 8,700 ± 200 BP (I-323) has been obtained from the base of an unexcavated, open midden site along the Carlton River estuary in southeastern Tasmania (Reber, 1965). Other examples of dated, but unexcavated, middens in the southeast include; one on Bruny Island dated to 6,050 ± 350 BP (I-316); and two others on Bruny and in the lower Derwent Valley dated to just over five thousand years BP (Reber, 1965).

Lourandos (1970) excavated a large midden at Little Swanport on the east coast and obtained basal dates of between 4,000 and 4,700 years BP. The midden consisted almost entirely of estuarine shell fish, especially *Ostea spp.*, and contained very low frequencies of terrestrial or scale fish remains. There was also a very low density of flaked implements, flaking floors and other structural features. With little or no evidence of other economic activities, Lourandos deduced that this site and others in the area represented very specialized oyster fishing camps.

The only inland site to have been excavated is Crown Lagoon (Lourandos, 1970). The cultural horizons occur within the upper sands of the lunette, and radiocarbon dates of 4,170 ± 80 BP (ANU-279) and 4,860 ± 95 BP (ANU-278) have been obtained from hearths. More information about this site will be given in Chapter 8.

From the distribution of dated archeological sites in Tasmania, excluding Bowdler's more recent evidence, Jones (1968) constructed a late glacial model of the Tasmania environment and early Aboriginal occupation. He suggested that most of island would have been inhospitable and was probably uninhabited, and that any human occupation would have been tightly coastal. Following the late glacial Holocene climatic amelioration and sealevel rise, the Aboriginals were probably forced inland as the sea reached its present height.

Using Shepard's (1961) sealevel curve and bathymetric data from Bass Strait, Jones estimated that the final severing of Tasmania from the mainland occurred at about 11,000 BP. He states (p. 200) that the " ... archaic character and conservatism of the Tasmanian artifact assemblages, and the absence of ... the new stone tools found on the mainland from about 5,000 BP onwards ... suggest that the Tasmanians and their ancestors had lived in isolation ..." since the island was cut off by the sea. Jones further suggested that the 11,000 years of isolation may be the most reasonable explanation of the physical differences between Tasmanian and mainland Aboriginals (Thorne, 1971a).

Summary - The above review indicates that very little, detailed Quaternary research has been done in the unglaciated lowlands of Tasmania and the extant literature deals only with isolated sequences from various parts of the island. There has been little or no attempt to correlate the successions and integrate the results, or to relate the known sequences to late Quaternary events in the glaciated highlands of the west. In addition, the piecemeal examination of occasional pollen spectra from widely distributed sites of very different ages has not been adequate to draw conclusions of environmental conditions during the last glaciation in Tasmania.

The best documented comparison of the Tasmanian sequences with those of the mainland is that of the postulated mid-Holocene arid period, which is based on incomplete evidence and doubtful interpretation. The present study is the first attempt to understand both the spatial and temporal relationships between the late Quaternary environment and Man in southeastern Tasmania.

CHAPTER 2

RESEARCH METHODS

The nature of Quaternary research requires an interdisciplinary approach to integrate systematic evidence from a diversity of subject matter. The aims encompass the reconstruction and understanding of past physical environments and organic associations, including human prehistory. Quaternary research achieves its greatest significance by synthesizing diverse evidence to produce a total environmental perspective.

The philosophical base of geographical research is directed toward understanding the spatial and temporal relationship between Man's cultural history and the physical environment (Hartshorne, 1959; Sauer, 1925). The field of Geography can provide the means through which integrated Quaternary research may be based. Butzer (1964) introduced the term *Pleistocene Geography* with reference to an integrated study dealing with the relationship between Man and the environment during the Quaternary Period. The research methodology utilizes techniques from geology, geomorphology, palynology, and climatology, radiometric dating, and attempts to unify them over the wider geographical perspective. Each technique incorporates its own strengths and limitations, but when taken together, the methods can be powerful tools for illumination of Quaternary environments.

This chapter presents the various techniques used in this thesis. Each was selected to give an understanding of the late Quaternary environment of Man in southeastern Tasmania.

<u>Geomorphic Mapping</u> - Maps of the exposed aeolian, alluvial and lacustrine deposits were compiled from enlargements (about 1 : 7,920 scale) of aerial photographs taken by the Tasmanian Lands Department in 1965. The site maps were then transferred by field inspection to topographic maps, where available. Large-scale maps of the two Midlands sites were not available and the geologic boundaries were determined in the field and mapped on the photo enlargements. Approximate elevations at these sites were transposed to the photo-maps from the available maps.

The relationship between terrace morphology and the modern channel gradient in the lower Jordan Valley was determined by third order levelling, and cross-profiles were constructed at selected points. Elevations are referenced to High Water Spring Tide (HWST) in the estuary. The height relations of the dry lake basin and associated lunette at Crown Lagoon were determined by levelling and are referenced to an arbitrary datum on the eastern shoreline.

<u>Stratigraphic Analysis</u> - The emphasis in this study is both geomorphic and stratigraphic. This approach was adopted because previous studies of the sandsheets were primarily based on morphological relations, and scarcely considered the stratigraphy and sequence of paleoenvironmental events revealed by the deposits. The major objectives were: 1) the identification of sedimentary and soil-stratigraphic units and their placement within a particular sequence; 2) the local and regional correlation of these units; and 3) the determination of a chronology of the events (Flint, 1971).

The stratigraphic units were studied in valley and gully exposures, drainage ditches, road cuttings and archeological excavations. As a rule the sandsheets are relatively undissected, and good exposures are rare and discontinuous. Information on buried deposits was obtained by augering and coring, and from soil pits. In some cases poorly exposed units were inferred from their geomorphic expression, soil texture and color. Most of the alluvial, lacustrine and aeolian deposits at Crown Lagoon were observed only in core and auger sections, and the sediments were obtained by a "Gemco" corer supplied by the Tasmanian Department of Mines. Type sections were established in representative localities, but these were never based on auger data alone.

The units were identified on the basis of their sediment characteristics, thickness and areal extent, range of variations and stratigraphic succession. The various deposits are divided into informal rock-stratigraphic units, and these as well as the landforms were mapped where possible. The aeolian sediments are well preserved at individual locations, but cannot be continuously traced between sites. Particular attention was paid to the physical relations of deposits, unconformities, and geomorphic associations (Richmond, 1962).

In addition to mapping the general geomorphic and stratigraphic associations, other physical, chemical and biological criteria were used to define individual units. These included textural analyses, soil profile data, geochemical determinations, clay mineralogy, nitrogen content, pollen analysis and archeological data. Many of these have been used primarily as descriptive parameters, although considerations of soil profile development and radiometric dating played an important role in correlation.

Textural Analysis - Samples from the main aeolian units at the principal sites were mechanically analyzed to provide a general textural description of the sediments. Each sample is thought to be fairly representative of the particular unit and the sampling interval was dependent on the local stratigraphic relations. The procedure of mechanical analysis closely followed that of Folk (1965) for unconsolidated sediments. The sand and mud fractions were separated by dispersion in water and wet sieving. The dry sand was then sieved at 0.5 ϕ intervals, and the proportions of silt and clay were determined at 1.0 ϕ intervals using a pipette method adopted from Krumbien and Pettijohn (1938). The gross percentages of sand, silt and clay for the samples are presented as a function of depth in the appropriate table which accompanies the descriptive section of each major stratigraphic unit.

Wherever possible, the parameters of mean (M_z), sorting (σ_1) and skewness (S_k) were calculated for the total sediment sample using the method of Seward-Thompson and Hails (1973) and programmed for the Elliot 503 computer by Chick (pers. comm.). However, these values could not be determined for many of the samples from the older aeolian deposits as these sediments were characterized by at least a bimodal grain size distribution of fine sand, silt and/or clay. The exact origin of the silt and clay cannot be addressed without detailed micromorphological studies, but the fines may have been either transported during deposition or formed through subsequent pedogenic alteration; or both.

Given the textural bimodality of the sediments, the limitations of the available laboratory equipment and the type of unimodal interpolation for which the computer program was designed, it was not possible to derive statistical values under the following conditions:

(a) M_z cannot be determined if there is more than 16% of the material in either end categories of the distribution curve as both the

16th and 84th percentile statistics are required in the calculation.

(b) Since σ_1 is a derived value, it cannot be computed in any case where M_z cannot be derived.

(c) Neither S_k nor kurtosis (K_G) can be determined if the clay content exceeds 5% as the 95th percentile statistic is required for computation. In addition, a detailed evaluation of these parameters would require much greater control of the fine end of the distribution curve than was possible with the available laboratory facilities.

Hence, the statistical treatment of the textural parameters was only of limited value in analyzing the significance of former sedimentary environments in this particular study. The grain-size characteristics presented here are essentially qualitative and are simply intended as an additional technique to describe the sediments. However, it is hoped that the grain size distributions may be useful as a comparative base for more detailed sedimentological research in the future.

Soil Profile Analysis - The study of soil profiles and their stratigraphic relations were useful techniques for subdividing individual deposits, and aided in both local and regional correlation. In addition, the profiles provided evidence for the post-depositional history of particular deposits and information on climatic change. The term "soil" in this study is taken to mean a profile of weathering (Frye, et. al., 1960; Richmond 1962) in the geologic sense and is thought to indicate some degree of ground-surface stability (Butler, 1959). A weathering profile defined here is a layer of material that is now or was in the past exposed at the earth's surface and shows evidence of chemical weathering sufficiently strong to be discernible in the field (Morrison, 1967).

Several profiles were identified as either relic, buried or exhumed soils. These were considered to be soil-stratigraphic units on the basis of their consistent recognition and local continuity (Amer. Comm. Strat. Nomen., 1961), but they have been mapped as informal units. As far as possible, the separate identity of each profile was determined by tracing it across a variety of substrates and the maximum age of each was established from the youngest geomorphic surface on which it was developed (Butler, 1959; Morrison, 1967). Where possible, the minimum age was determined by observing the particular profile in a number of buried occurrences.

Numerous profiles were observed at each site, but the descriptions in the text were made at the type sections. Most profiles are truncated by erosion surfaces and complete profile data are not available. In general, the profiles were described from well drained sites on gentle slopes to minimize variations caused by local environmental factors. This procedure better facilitated profile comparisons between sites.

The method of describing soil profiles and the nomenclature of soil horizons primarily followed that recommended by the Soil Survey Manual of the U.S. Department of Agriculture (Soil Survey Staff, 1962), but certain terms have been borrowed from Brewer (1964) and Stace et. al., (1968). The soil colors are those of the Munsell system (Munsell Soil Color Chart, 1954). Soil reaction (pH) was obtained by using a small field kit produced by the C.S.I.R.O. At many localities soil textures were based on field examination without mechanical analysis and the method of field texture determination followed the procedure outlined by Corbett (1969).

Geochemical Determinations - Iron and aluminum oxide values were used as a relative index of weathering for the soil profiles observed at the major sites. Free iron oxide (sodium dithionite reducible iron) was determined from the fine earth fraction by the colorimetric thiocyanate method following the procedure outlined by Jackson (1956) and is expressed as percent extractable iron ($E_{Fe_2O_3}$). Total iron ($T_{Fe_2O_3}$) was determined by bulk sample decomposition using the HF-$HClO_4$ digestion technique and the percent was measured by the colorimetric thiocyanate method. The percent total aluminum ($T_{Al_2O_3}$) was determined from the digested solutions by atomic absorption spectrometry using a Varian AA_6 instrument against known standards. These values are presented as a function of depth in the descriptive tables which accompany the major sites.

Clay Mineral Determinations - The clay mineralogy of soil horizons at the major sites was also used as a descriptive parameter in analyzing the degree of weathering. X-ray diffraction of clay samples was carried out on a Philips diffractometer using CuK_a radiation with scanning over the range 2^o - 44^o 2 θ. The samples were obtained from the clay fraction (>9.0 Ø). Free iron oxides were removed by the sodium dithionite method and the samples were saturated with Mg^{+2} using the procedure outlined by Jackson (1956). The treated clay suspensions were transferred to glass slides to form oriented aggregates. X-ray diffraction was carried out after air-drying, ethylene-glycol solvation and heating to 600^o C. The clay minerals were identified by reference to Brown (1961) and Jackson (1956). In the tables of analytical data for the various profiles the clay minerals are identified by the following symbols:

Mt	Montmorillonite	M/I	Montmorillonite/Illite Interstratification
I	Illite	Q	Quartz
K	Kaolinite		

The relative amounts of clay minerals were estimated from the areas enclosed by the strongest diffraction peaks and are indicated by the following:

x	small	xxx	large
xx	moderate	xxxx	dominant

Nitrogen Content - Total nitrogen was determined for the upper lacustrine sediments at Crown Lagoon and was used as a rough index of the trophic stage (Horie, 1965). High amounts of nitrogen are thought to indicate a relatively eutrophic environment, while lower amounts suggest relatively oligotrophic or mesotrophic conditions. The nitrogen context was determined by the micro-kjeldahl method and the analyses were done by the C.S.I.R.O. Division of Soils in Hobart.

Archeological Methods - Several controlled excavation pits were dug at the Glenfield and Old Beach sites to determine the relationships between Aboriginal cultural horizons and the aeolian stratigraphy. The method consisted of digging vertical test pits, usually 1 m square, and excavating 10 cm spits by means of trowelling. All material was passed through a 3 mm mesh garden sieve, and the artifacts recovered from each spit were collected and drawn. No attempt was made to classify the artifacts according to typological associations with other sites in the area.

Pollen Analysis - Pollen analysis was used to investigate the nature and composition of past vegetation communities. The technique was primarily used in interpreting the depositional history of the upper lacustrine sediments from Crown Lagoon, but reconnaissance analyses were carried out on some alluvial and aeolian sediments. A 2 m core was obtained from the approximate center of Crown Lagoon and the sediments were analyzed for pollen at 10 cm intervals. Spot samples were collected from vertical exposures in the other deposits with the sampling interval dependent on the local stratigraphic relations.

The nature of past vegetation at a site can be inferred by relating the modern pollen distribution to the vegetation community surrounding the site. Once this relationship is understood, changes in the vegetation community through time may be deduced from the pollen assemblages preserved in the stratigraphic record (Davis, 1969; Martin, 1963). Modern pollen samples can be obtained from a variety of sources, including air samples, moss polsters, cattle tanks and soil surface samples (Hansen, 1949; King and Sigleo, 1973; Martin, 1963). Soil surface samples were selected to study the modern pollen rain, as it was desirable to try to duplicate as closely as possible the depositional environment of the fossil pollen record (Faegri and Iversen, 1964; Mehringer, 1967).

Two modern surface samples were taken from within and immediately adjacent to a small marsh 600 m northeast of the lake basin at Crown Lagoon. This location was selected to avoid possible contamination of the lake floor due to ploughing, grazing and settlement. A multiple subsample technique, modified from Hevly, Mehringer and Yocum (1965), was used to reduce the possibility of overrepresentation of local pollen types. This consisted of collecting 30-40 small subsamples of surface sediments at intervals of 10 paces in a 50 m square area. The same procedure was used to sample the modern marsh sediments immediately adjacent to the surface soil site. All of the subsamples comprising one sample were mixed in a polythene bag before processing. The composition of the dominant vegetation at the sampling sites was noted, although no attempt was made to classify the communities by phytosociological parameters other than relative cover.

The extraction followed the standard HF digestion technique used for sediments suspected to have low pollen concentrations (Martin, et. al., 1961; Mehringer, 1967), and acetolysis (Erdtman, 1943) was used to remove resistant organic material. Following extraction a drop of the relatively pure pollen matrix was mounted on a glass slide in glycerol and stained with basic fuchsin for counting. The excess pollen residue was placed in vials and stored.

The pollen were identified and counted using a Wild binocular microscope at 600X. A pollen reference key is not available for the plant families of Tasmania and in many cases generic determinations could not be made. The pollen identifications were made by reference to standard keys (Erdtman, 1957; Faegri and Iversen, 1964; Kapp, 1969) and by comparison with collections supplied by the Department of Botany, University of Tasmania.

The pollen of Myrtaceae (Pike, 1956) is an extremely difficult group to subdivide and the available key is based on perfectly preserved herbarium specimens. *Eucalyptus* pollen was differentiated on the basis of its syn- or more commonly parasyncolpate form and characteristic thickening of the exine near the apertures. However, the possibility exists that some *Melaleuca* pollen has been identified as *Eucalyptus*, as these two pollen species may appear to be morphologically similar if not well preserved.

"Cheno-ams" is an artificial group referring to various pollen genera in the family Chenopodiaceae which are indistinguishable from the genus *Amaranthus* of Amaranthaceae (Martin, 1963). Grass pollen was not identified below family level and aquatic pollen was only identified to genus level. The pollen of the subfamilies Liguliflorae and Tubuliflorae of the Compositae are morphologically distinct. The latter subfamily was divided into two artificial pollen types; high and low spine Compositae (Hevly, Mehringer, and Yocum, 1965). Low spine composites are generally wind-pollinated and include members of the tribe Ambrosieae, while the high spine Compositae are considered to be insect pollinated.

The method of counting was a variation of the double fixed sum procedure used when certain pollen types are suspected of either long distance or local over-representation (Adam, 1965; Mehringer and Haynes, 1965). In this study, an initial sum of 200 pollen grains was counted from each slide or series of slides composing one sample and no pollen types were excluded from the sum. Aquatic pollen types were subtracted from this sum and a second sum of 200 grains was counted for all non-aquatic pollen types. Spores were excluded from both sums and in most cases were not identified. Both pollen sums for each sample are plotted against core depth to illustrate changes in relative frequencies through time. The pollen data are given in Appendix 2.

CHAPTER 3

LOCATION AND DESCRIPTION OF THE STUDY AREAS

This chapter provides an environmental data base with which to evaluate the spatial and temporal relationships between climatic change and landform evolution. The first section contains a brief overview of the most salient geologic, climatic and biogeographical characteristics of the Tasmanian environment. The second part provides more detailed information about the study areas in the lower Derwent Valley and Midlands, and identifies critical environmental factors which have influenced local geomorphic processes in the past.

The Tasmanian Environment - Tasmania is a small, continental island lying in the Indian Ocean, some 225 km south of the Australian mainland (Figs. 1 and 2). Much of the island's interior consists of rugged mountain ranges and very little of the land area lies close to sealevel. The Western Highlands are northwest-southeast mountains, some of which rise to just over 1,600 m. The core of the island is the broad Central Plateau, a prominent, tabular landform bordered on the north and east by a 1000 to 600 m scarp which slopes gently southeastward. The Eastern Highlands are low coastal mountains with an average summit height of 300 to 400 m. Situated between the Central Plateau and the low eastern ranges is the Midlands, the largest area of inland plains on the island.

The western ranges are composed mainly of pre-Carboniferous rocks aligned in parallel fold structures, while the Central Plateau is a single sill of Jurassic dolerite. In the Midlands, southeast and east, the Paleozoic rocks are buried by Permian and Triassic sediments into which

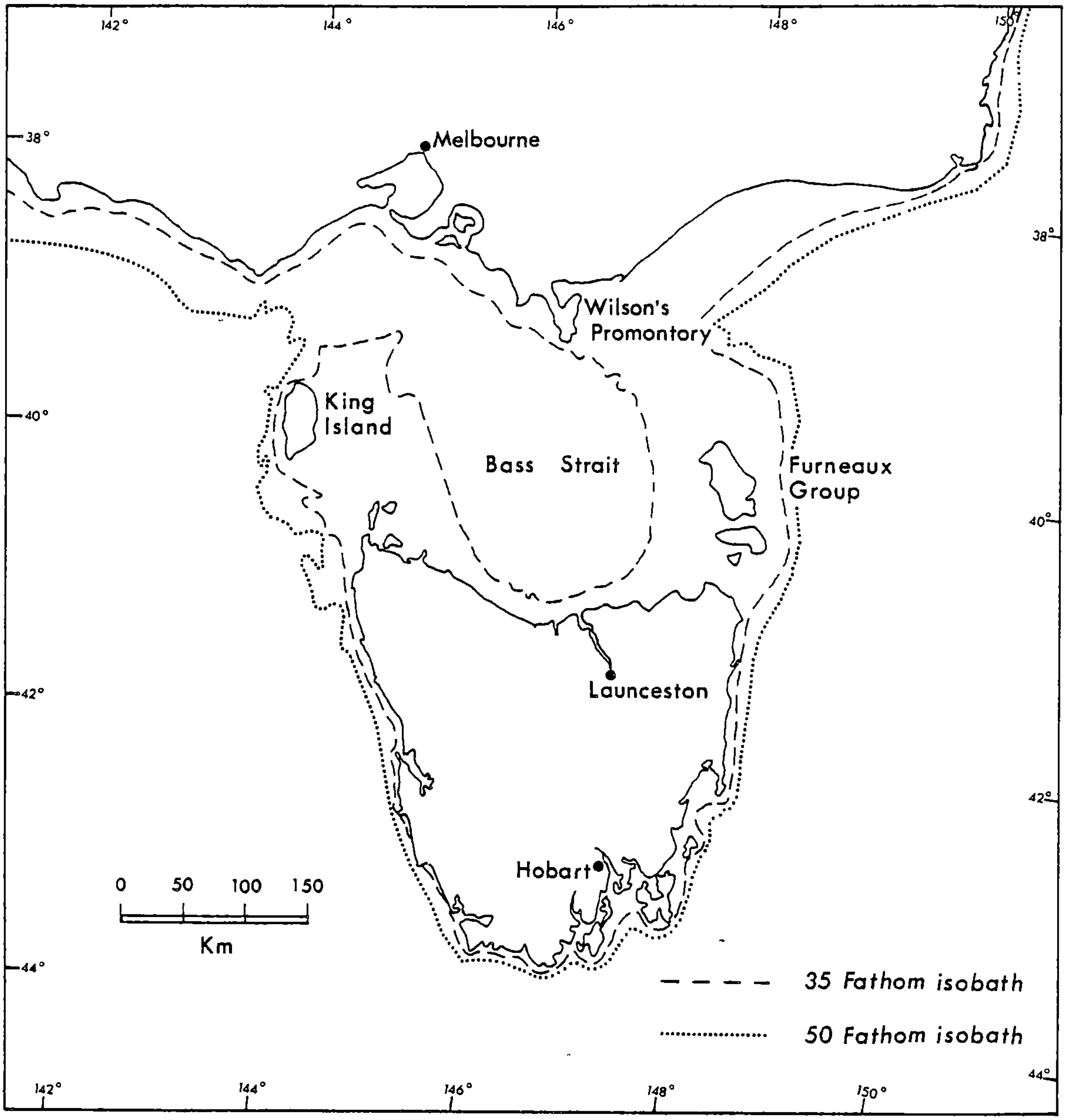


Figure 2. Map of Tasmania and southeastern Australia. Bathymetry after Jennings (1971) and RAN hydrographic charts.

the dolerite has intruded at various levels. The Midlands is a broad structural trough formed by extensive normal faulting during the late Cretaceous and/or early Tertiary. Widespread faulting at this time produced smaller horst and graben structures in the lower Derwent Valley, many areas of the southeast and in the Launceston Basin. Late Tertiary volcanics and sedimentary rocks occur throughout the Midlands and southeast, but are most widely distributed in the north (Banks, 1965; Davies, 1965).

Most Tasmanian soils are moderately to strongly leached and at higher elevations, consist mainly of podzolics. Moor peats and Alpine humus soils are common in large areas of impeded drainage, such as the Central Plateau. Prairie soils, black and brown earths and minimal podzolics are prevalent over most of the eastern half of the island (Leamy, 1961; Loveday, 1955; Nicolls and Dimmock, 1965).

Superimposed over the island's diverse topographic structure is a complex fabric of local climates and vegetation associations (Table 1). Located in the mid-latitude westerly wind belt and dominated by southern oceanic air masses, the island has an overall temperate marine climate; however, the alignment and elevation of the western mountains create a pronounced rainshadow in the low-lying Midlands and southeast. The island is large enough to show moderate continental effects on temperature, especially in the southeast Midlands where the mean daily range at most stations exceeds the mean annual range (Langford, 1965).

The vegetation consists of three major formations; temperate rainforest, austral-montane shrub and sclerophyll forest. Rainforest extends from sealevel to about 1,200 m in the moist highlands, with *Nothofagus cunninghamii* being the dominant arboreal species. The

TABLE 1

GENERALIZED ENVIRONMENTAL DATA FOR TASMANIA

(Source; Atlas of Tasmania, 1965)

COMPONENT	WEST COAST	WESTERN HIGHLANDS	CENTRAL PLATEAU	MIDLANDS	EAST COAST	NORTH COAST
Geology	Unmetamorphosed, pre-Carboniferous igneous and sedimentary rocks; faulted and folded during periods of orogeny. Quaternary glacial, periglacial and marine deposits.	Metamorphosed, pre-Cambrian sedimentary rocks; deformed during Frenchman Orogeny (pre-Cambrian) and Tabberabberan Orogeny (Devonian) Quaternary glacial and periglacial solifluction deposits.	Single, massive sill of Jurassic dolerite; Permian glacial and Triassic continental sediments exposed along the margins; small areas of Tertiary basalt; Quaternary glacial and periglacial deposits.	Triassic sediments (mainly sandstones) and Permian marine deposits intruded by Jurassic dolerite; area extensively faulted during early Tertiary; Tertiary basalt and continental sediments. Quaternary periglacial (?), alluvial, lake and aeolian deposits	Jurassic dolerite and Triassic sediments; Tertiary basalt and sediments; Quaternary alluvial, periglacial solifluction deposits at higher elevations; Quaternary marine sediments.	Pre-Carboniferous igneous and sedimentary rocks, Permian and Triassic sediments intruded by dolerite; Tertiary basalt and continental sediments; Quarternary marine and coastal deposits.
Meteorology						
mean annual precipitation	1000 - 1500 mm	2500 - over 3000 mm	1000 - 2000 mm	500 - 600 mm	500 - 800 mm	700 - 1200 mm
mean annual temperature	10 - 12° C	8 - 10° C	10° C	10 - 13° C	12 - 14° C	12° C
mean annual evaporation	750 - 1000 mm	less than 750 mm	750 - 1000 mm	600 - 1200 mm	800 - 1500 mm	600 - 1000 mm
Vegetation	Coastal heath Sedgeland Temperate Rainforest "Wet" Sclerophyll Forest	Temperate Rainforest Austral - Montane Shrubbery	Austral - Montane Shrubbery "Wet" Sclerophyll Forest	"Dry" Sclerophyll Forest Eucalypt Savannah Grassland	"Dry" Sclerophyll Forest Coastal Heath Isolated areas of rainforest	Coastal heath Montane Woodland Temperate Rainforest "Wet" Sclerophyll Forest "Dry" Sclerophyll Forest
Soils	Podzol Skeletal Moor Podzol Peats	Podzolics Skeletals	Alpine Humus Moor Peats Podzolics	Prairie Brown Earths Black Earths Podzolics "Lateritic" Podzolics	Podzolics Podzols Alpine Humus	Podzols Calcareous Sands Acid Swamp Krasnozems Podzolics

austral montane shrub consists mainly of Epacridaceous-Proteaceous species which occur above 1,000 m on the Central Plateau and in higher, poorly drained valleys of the west. Sclerophyll forest, dominated by *Eucalyptus spp.* is distributed throughout the dry, eastern half. Although strongly influenced by climate, the vegetation is often determined by variations in topography, edaphic conditions, fire and/or frost frequencies. Complex ecotones, resulting from any or all of these factors, occur throughout the major formations. The most significant are the wet sclerophyll forest (Gilbert, 1958); the West Coast sedgeland; and the eucalypt savannah and grassland of the Midlands (Jackson, 1965; 1968).

This review demonstrates the broad physical and biogeographical diversity that characterizes the modern Tasmanian environment. Climatic variability is largely determined by geologic structure and because of the alignment of the highlands, major environmental differences exist between the western and eastern portions of the island. Past climatic changes would have accentuated these differences, particularly in the unglaciated lowlands.

THE STUDY AREAS

Location - The principal sandsheets in the lower Derwent Valley are at Glenfield, Old Beach and Bridgewater, some 20 km north of Hobart (Fig. 3). Other sandsheets and dunes were examined in less detail to place the main sites in a regional framework. The Midlands sites are located at Crown Lagoon near Lemont and White Lagoon north of Tunbridge (Fig. 4). Both are small lake basins with lunettes along their southeastern margins.

The lower Derwent Valley, a small graben drowned by the sea, is bordered on the west by an uplifted, mountainous plateau, with Mt. Wellington (1,270 m) being the highest and most conspicuous summit. To the east the

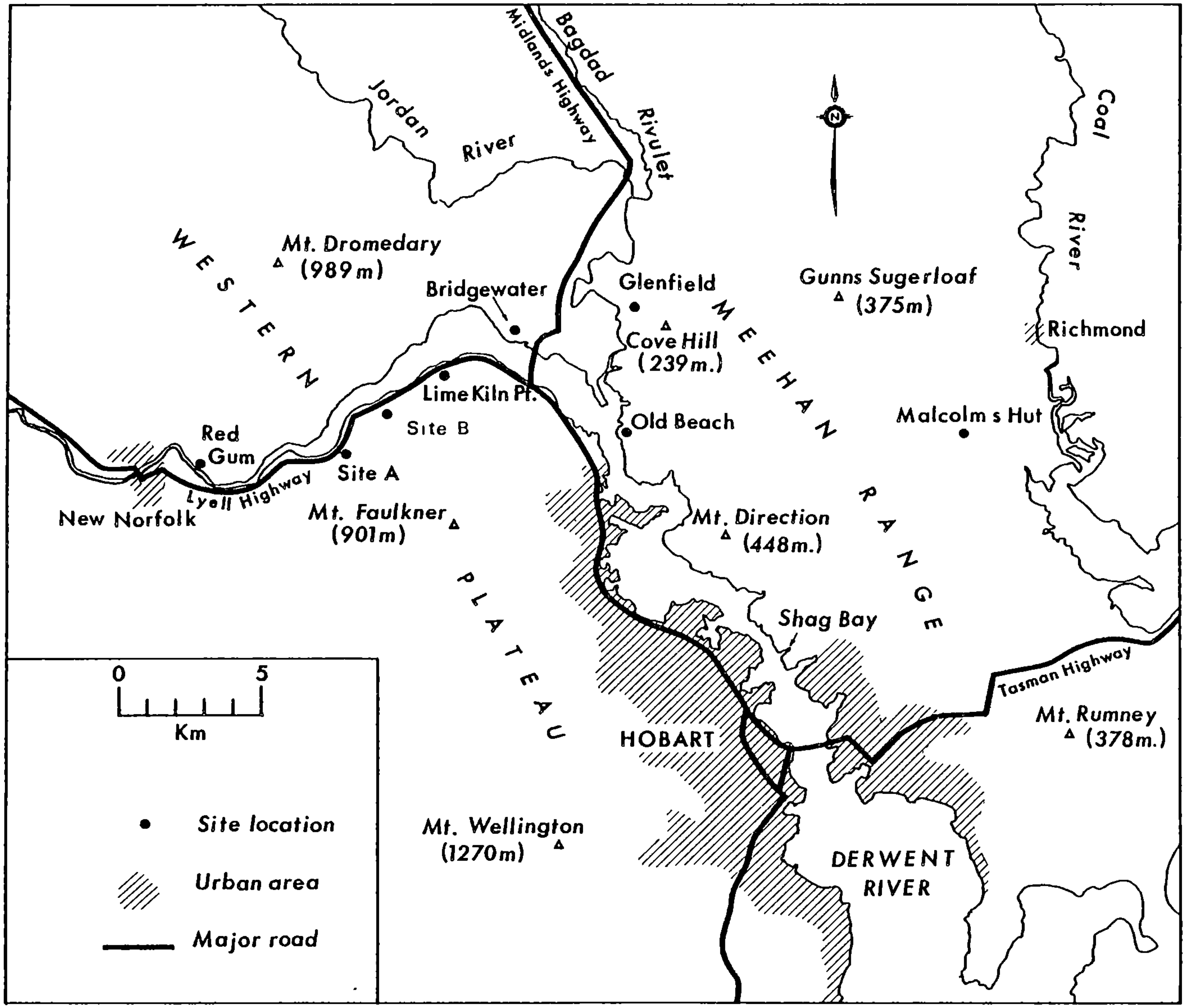


Figure 3. Location map of the lower Derwent Valley

land forms a lower and less rugged range with an average height of some 300 to 400 m. Above Bridgewater, the valley narrows and turns sharply west where it crosses the axis of the high plateau; here, the estuary is confined between steep slopes leading to Mt. Faulker (901 m) on the south and Mt. Dromedary (989 m) to the north. From New Norfolk - the tidal limit of the estuary - the Derwent River follows a northwesterly course to its source at Lake St. Clair, some 150 km distant in the Central Highlands.

The Midlands is bordered on the west by the heavily wooded, escarpment of the Central Plateau, and on the east by the gently sloping front ranges of the Eastern Highlands. The region contains many smaller fault valleys and plains situated between low hills and plateaus. The major drainage system in the north is the Macquarie River which has its sources in the Eastern Highlands. In the south, the main tributaries, including the Jordan River, are much smaller and flow intermittently. Small lakes and lagoons are common in the Midlands; the largest are at Lake Tiberias, Lake Dulverton and Grimes Lagoon. The lakes, many of which have low lunettes along their southeastern margins, occur either as isolated features, or are grouped in small clusters on some valley floors and the adjacent interfluves. Most are at least seasonally dry, except where water levels are maintained artificially.

Geology and Soils - The pre-Quaternary rocks of both study areas are similar and range in age from Permian to late Tertiary (Appendix 1). Triassic continental sediments, consisting mainly of friable protoquartzites and feldspathic sandstones, are the most widely distributed rocks, and have provided the main source of clastic material for the sandsheets and lunettes. Triassic sandstones are most extensive below Bridgewater in the lower

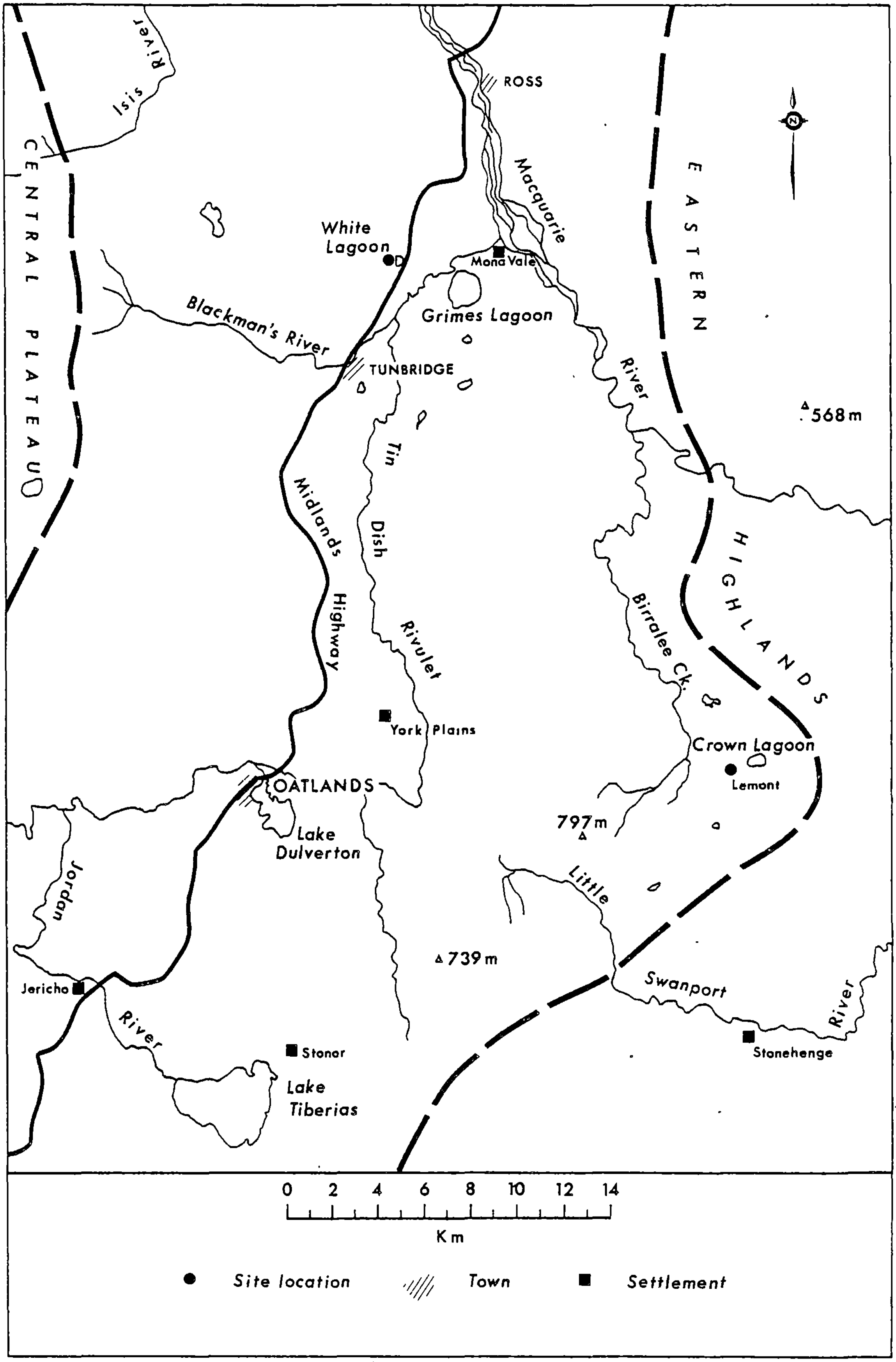


Figure 4. Location map of the Midlands

Derwent Valley where they crop out on both sides of the estuary. Similarly, most of the faulted valleys of the Midlands are underlain by Triassic sediments.

The younger Mesozoic rocks have been intruded by massive sills and transgressive sheets of Jurassic dolerite. Resistant to erosion, the dolerite forms prominent cliffs with steep facing scarps. The high plateau west of Hobart is a single body of dolerite some 450 m thick. The dolerite dominates the landscape in the Midlands and it forms low horsts and residuals adjacent to the down-faulted valleys. Late Tertiary basalts and continental sediments occur in both regions. (McDougall, 1959; Spry and Banks, 1962).

In the lower Derwent Valley, sediments of Quaternary age include alluvial and/or estuarine terrace deposits up to 20 m above sealevel; extensive periglacial debris on the upper slopes of the valley; alluvial fans in some of the low tributary valleys between Bridgewater and New Norfolk; and numerous small aeolian sandsheets and dunes. The alignment of the aeolian landforms is roughly parallel to the prevailing westerly wind direction, and the deposits along the margins of the Derwent border alluvial source areas now drowned by the sea.

Quaternary sediments in the Midlands consist mainly of thin mantles of probable periglacial material on the higher slopes; thick alluvial valley fills and adjacent terraces; small dune fields north and east of the Macquarie River; and the lunettes and their associated lacustrine sediments. The small lunettes, deposited by west to northwesterly winds, consist of both fine and coarse grained sediments.

Shallow podzolic and brown soils are most common on the Permo-Triassic sediments in both areas. Locally, rendzina and terra rossa soils are developed on Permian limestones in the lower Derwent Valley. Podzols are also formed on some Triassic sandstones, but these soils are generally thin and discontinuous. Podzolic, prairie and black soils occur mainly on the dolerite. Black soils, similar to those on dolerite, also occur on the basalt. Well developed podzolic and solodized-solonetez occur on the older river terraces in both areas. In the lower Derwent Valley yellow brown soils are developed on periglacial deposits found above 600 m (Cowie, 1959; Dimmock, 1955). The soils formed on and within the alluvial fan and aeolian sequences have not been described, but podzolics and red-brown earths occur on some of the fans and aeolian deposits.

The sandstone soils, and those which occur on aeolian deposits, are especially prone to erosion following clearing of the vegetation and heavy grazing pressure due to the friable nature of the A horizons. The author has observed disturbed profiles in many low open areas, and in some localities, the truncated B horizon is exposed at the land surface. Locally, the disturbed A horizons have been redistributed by westerly winds or sheetwash has transported the predominantly sandy debris downslope.

Climate - Both areas are characterized by relatively warm summers, cool winters and an even distribution of precipitation. Climatic data for Hobart and Oatlands, the longest recording stations, are summarized in Table 2.

TABLE 2

CLIMATIC DATA FOR HOBART AND OATLANDS
(Commonwealth Bur. Meterol., 1972; Hobart Weather Bureau)

Station and elevation	Period of record	Mean Annual Precipitation (mm)	Mean Temperatures (°C) Annual	January	July	Mean Annual Evaporation [a] (mm)	Frost Frequency [b] (days/yr)
Hobart (130 m)	1883-1974	633	12.4	16.5	7.7	695	29.2
Oatlands (450 m)	1883-1960	569	9.9	14.6	5.2	745	149.6

a. At Hobart, evaporation determined from an Australian Standard Tank; at Oatlands, it has been calculated from the mean monthly saturation deficit.

b. Screen temperatures of 2°C or less. Totals include "heavy" frosts (0.9°C or less).

The low precipitation totals result from the rainshadow created by the ranges and mountains to the west, but this effect is more pronounced in the Midlands. Both areas are marginally continental, but being further inland, the Midlands experience a greater diurnal temperature range than does the lower Derwent Valley. Mean annual and seasonal temperatures are slightly higher in the lower Derwent Valley than most parts of the Midlands due to the moderating effects of the sea and the lower elevations. High seasonal temperatures cause a moisture deficit in both areas, and the low precipitation effectiveness results in significant variations in the water table and in river flow.

Temperature and precipitation in both areas vary considerably with elevation and local topography. In the lower Derwent Valley, low land, particularly on the eastern side, receives about 100 mm less precipitation than Hobart. As these areas are not shadowed to the same extent by the high plateau, temperatures tend to be a few degrees higher on the east.

With elevation, precipitation increases to about 1,400 mm on the southwestern slopes of the high plateau, but drops to near 800 mm on the summit of Mt. Wellington.

Annual precipitation in the Midlands decreases toward the scarp of the Central Plateau, but the driest areas are near Ross and Tunbridge (495 mm). In contrast, precipitation is about 800 mm on the edge of the Central Plateau and increases to over 3,000 mm in some portions of the Western Highlands. Totals are about 760 mm in the Eastern Highlands, and at Crown Lagoon, 22 km east of Oatlands, precipitation is estimated to be near 680 mm. Mean annual temperatures are similar at most stations in the Midlands, but there is a slight increase from south to north.

At Hobart snow occurs about once a year in areas below 300 m, but rarely remains for more than a day. Snowfalls occur about fives times more frequently at Oatlands and in the southern Midlands. In both regions areas of higher ground receive light snow several times a year and above 500 m, falls are heavier and more frequent. (Atlas of Tasmania, 1965; Hobart Weather Bureau). Snowmelt following thaws can contribute to local flooding, particularly in the Midlands and small tributary valleys adjacent to the Derwent.

Frost frequency is one of the most significant climatic differences between the two areas. Due to its inland location and higher elevation, the Midlands experiences nearly fives times more frosts than the lower Derwent Valley and about twice as many heavy frosts annually. The Central Plateau is the main source of the cold air which drains into the Midlands. Cold pools and temperature inversions form in many of the low valleys. A similar effect occurs in the lower Derwent Valley, but here the incidence of frost is much more variable due to the moderating effect of the sea.

The highlands have a much shorter frost-free period and frosts occur in every month on the summit of Mt. Wellington and probably on the Central Plateau. For example, Mt. Wellington averaged 233 light frosts and 169 heavy frosts annually in the 11 year period 1960 - 1971 (Hobart Weather Bureau). Frost data for the Central Plateau are not available, but the incidence is probably similar to that of Mt. Wellington, if not higher. As yet there are no detailed soil temperature records from either area by which to assess the effects of near-surface freezing. In the lower Derwent Valley, occasional frost heave of the surface 2 cm of soil occurs on bare areas of gardens and fields near sealevel. Frost heave is more frequently on the summit of Mt. Wellington with the growth of needle ice to 2 - 3 cm depth, often in superimposed layers (Colhoun, pers. comm.).

Table 3 shows a frequency analysis of the potential number of days in which fine sand could be mobilized by wind at New Norfolk and Oatlands given dry, unvegetated surface conditions. These data are useful in assessing the potential for modern wind erosion and provide a generalized data base by which the paleowind conditions responsible for sandsheet and lunette deposition can be evaluated. New Norfolk was selected as the main recording station in the lower Derwent area because the topography and open exposure of this station is similar to that where the majority of the sandsheets are found.

At both stations the greatest proportion of high intensity winds are from the southwest, west and northwest. West and southwesterly winds occur in all seasons and are associated with both cyclonic and anticyclonic circulation patterns. High intensity west and northwesterly winds are particularly common from late spring through fall, and are usually related to slow moving

TABLE 3

FREQUENCY OF POTENTIAL SAND-TRANSPORTING DAYS

AT NEW NORFOLK AND OATLANDS GIVEN DRY, UNVEGETATED SURFACE CONDITIONS[1]

A. NEW NORFOLK

DIRECTION	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC
N												.02
NW	.04	.02	.01	.04	.01	.03	.04	.02	.03	.02	.03	.04
W	.18	.16	.11	.13	.09	.05	.04	.07	.11	.17	.15	.08
SW									.01	.01	.01	
S	.01										.01	
SE								.01				.01
E	.05	.09	.02							.01	.01	.05
NE												.01

B. OATLANDS

DIRECTION	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC
N	.05	.03	.02	.02	.01	.01	.01	.01	.03	.05	.07	.04
NW	.07	.04	.01	.02	.01		.04	.03	.02	.04	.03	.05
W	.03	.04	.05	.04	.04	.03	.03	.06	.10	.11	.12	.07
SW	.05	.04	.04	.01	.05	.04	.04	.02	.06	.04	.06	.04
S	.02				.01		.01		.02	.01	.01	.01
SE											.01	
E									.01		.01	
NE	.01						.05		.01	.01		

1. Year of Record 1965–1973 measured at 1500 hrs; threshold velocity for fine sand $\geq$4 m/sec. (Olson, 1968).

anticyclones which produce winds with trajectories across the hot, dry mainland (Langford, 1965). Variations in wind intensity and direction between the stations are most likely related to local differences in topography. In this respect, the Midlands is a more open landscape and less likely to be affected by wind funneling than the mountainous lower Derwent Valley. This factor could explain the higher proportion of southwesterly winds at Oatlands as compared with New Norfolk.

The wind data indicate that the potential for sand transport by wind is very low in the present environment. The alignment of the lower Derwent sandsheets indicates the persistence of the westerly wind component over time, while the general orientation of the lunettes suggests that these dunes were deposited under the influence of northwesterly winds, probably during the summer months. Divergence between the alignments of these landforms does not imply that they were formed under different wind regimes, rather the westerly orientation of the sandsheets reflects channeling of northwesterly winds down the lower Derwent Valley.

Vegetation - The main vegetation formation of southeastern Tasmania is the dry sclerophyll forest, usually dominated by *Eucalyptus spp* (Jackson, 1965). Unfortunately, there are few published accounts of the forest, but recent studies indicate that it contains complex ecotones that result from variations in local climate, edaphic conditions, and fire and/or frost frequency (Kirkpatrick, pers. comm.).

The vegetation of the lower Derwent region is broadly zoned according to altitude with a eucalypt woodland or forest on the lower slopes; a low open forest on the higher slopes, and a subalpine open forest dominated by *Eucalyptus delegatensis* above 800 m on the high plateau. On the summits there is a subalpine woodland of *E. coccifera* (Martin, 1940).

In the low areas adjacent to the sandsheets, the eucalypt forest has been either eliminated or is much modified due to extensive European disturbance. Where present, the vegetation is usually dominated by *E. obliqua, E. globulus* and *E. viminalis* with a broad leaf or sclerophyll shrub understory. *Casuarina stricta,* a large shrub or small tree, is common and locally dominant on dry, north-facing slopes. The isolated lower slopes on the eastern side of the valley have a predominantly closed, herbaceous ground cover consisting mainly of *Poa rodwayi* and *Themeda australis* (Kirkpatrick, pers. comm.).

The sclerophyll forest of the Midlands consists of three main associations: grassland, savannah and forest. The dense grassland occurs mainly on the floors of valleys and basins, and usually consists of *Poa spp.* and *T. australis*. *E. pauciflora* occurs through the grassland, and is relatively common along the valley margins. The effects of grazing on the grassland have been considerable, and in heavily disturbed areas, *Themeda* is usually eliminated due to competition from introduced species.

The savannah is distributed over most of the low, hilly country and is dominated by the *E. ovata - E. pauciflora* association. Minor trees or tall shrubs, such as *Banksia marginata* and *Acacia melanoxylon* are important subdominant members in the savannah,and the closed ground cover consists of *Poa spp., T. australia* and numerous small composites. The grassland and savannah are replaced by thick forests on the surrounding low hills and ridges. In general, *E. pulchella* and *E. viminalis* are dominant on dolerite, while *E. amygdalina* and *E. viminalis* are more common on Triassic sediments. Lesser trees or tall shrubs such as *B. marginata, Exocarpus spp.* and *Bursaria spinosa* are scattered throughout the forest. *Casuarina stricta* is locally abundant on drier upland slopes. Mesic communities occur locally in deep, south facing gullies and contain the tree ferns frequently associated with larger eucalypt species such as *E. regnans* and *E. globulus* (Jackson, 1965).

The extent to which a natural division occurs between the savannah and grassland communities, and the sclerophyll forest is problematic. The Midlands region was burned extensively by both the Aboriginals and Europeans, and this factor undoubtedly helped to maintain the low tree density in the savannah and grassland. Diaries of early travellers reported that the valleys of the Midlands were largely devoid of trees and contained luxuriant grasslands prior to the main impact of European settlement (von Stieglitz, 1960). Jackson (1965) suggested that the grassland and savannah are a cultural artifact of Aboriginal burning and do not represent climax communities. However, he later indicated (1973) that, in the areas of high frost incidence on the Central Plateau, most eucalypt species are eliminated and replaced by apparently more resistant taxa, such as *E. pauciflora* and grasses.

A similar relationship between frost and eucalypt taxa probably exists in many areas of the Midlands. Here, the effects of frost are accentuated in the smaller valleys due to cold air drainage and local temperature inversions. The relatively high frost frequency in the Midlands could explain the dominance of *E. pauciflora* in both the grassland and savannah. Fire frequency does not seem to be the most important factor in determining variation within the sclerophyll forest environment as all the eucalypt species appear adapted to fire through avoidance and protection mechanisms, and many actually benefit from frequent burning (Kirkpatrick, pers. comm.).

Summary - Brief consideration of the environmental data is useful in assessing the relative effectiveness of various geomorphic processes which operate on the landscape of southeastern Tasmania. The dominant processes include fluvial erosion, soil formation and local mass wasting (Davies, 1965). In general the lowlands are relatively stable in the present climate, and there is little evidence of contemporary aeolian erosion in the interior, except on sandy groundsurfaces disturbed by the activities of Man.

The sandsheets and lunettes are now stabilized by vegetation. If changes in critical environmental factors, such as temperature, frost frequency and precipitation, were to alter the density and/or structure of the vegetation, aeolian erosion could again occur. In addition, wind velocities necessary to initiate widespread aeolian activity would be higher than at present.

Frost-related, mechanical weathering at higher elevations is extremely limited in the present environment due to relatively warm temperatures and the stabilizing effect of the vegetation cover. However, the short-term frost records from Mt. Wellington suggest that, if a reduction in temperature occurred, the incidence and seasonal distribution of heavy frosts would increase, along with the production of periglacial debris at favorable locations. Any reduction in the vegetation cover due to colder conditions should increase the potential for slope erosion and mass wasting, particularly on Triassic sandstones and other friable groundsurfaces. Under these conditions, snowmelt should be an important factor in slopewash erosion and fluvial transportation of debris.

In the present climate, there is little or no sedimentation in the small lake basins of the Midlands, except where water levels are maintained artificially. Given the large seasonal moisture deficit, it is apparent that low water levels are mainly controlled by temperature and not solely by precipitation. High water levels could be maintained at least seasonally in an environment where evaporation is less, and/or precipitation higher than present. Alternatively, lower evaporation rates, combined with greater seasonal runoff, could provide the necessary water balance to sustain high lake levels and initiate lacustrine sedimentation in the basins.

Given the evidence of extensive glaciation of the Highlands of Tasmania during the Pleistocene, colder climates at these times would have significantly modified the present landscape stability in the unglaciated lowlands. With changes in climate and the effects on vegetation cover, periglacial and aeolian processes were probably intermittently important in the lower Derwent Valley and Midlands. The following chapters describe and analyze the empirical evidence of climatic change, as well as that of Aboriginal occupation, and evaluate their role in aeolian landform evolution during the late Quaternary period.

PART II

LOWER DERWENT VALLEY SITES

CHAPTER 4

PRINCIPAL SITES OF THE LOWER DERWENT VALLEY

This chapter presents the descriptive evaluation of the geomorphic, stratigraphic, and archeological evidence from the principal aeolian sandsheets at Glenfield, Old Beach, and Bridgewater in the lower Derwent Valley (Fig. 3). The first section briefly describes high level, alluvial and scree deposits adjacent to the sites and the second considers the sandsheets.

I. Alluvial Deposits

Introduction - A general survey of high level, alluvial sediments exposed near the sandsheets was conducted in order to outline relationships between periods of fluvial deposition and aeolian activity in the past. It must be emphasized that only tentative correlations are presented to explain the origin of these deposits as a detailed study of the alluvial history of the valley lies outside the scope of this research.

The oldest deposits of Quaternary age in the area may be the alluvial sands, silts and gravels which border the Derwent and its major tributaries. These sediments are exposed to 3-15 m above HWST, but are not continuous and generally occur as isolated alluvial remnants protected by bedrock faces. Their thickness varies considerably and the deposits overlie strath terraces cut at different levels and across a variety of rock types. The strath surfaces could have formed during a different period of prolonged lateral planation and each may be unrelated to any other surface. This consideration could also apply to the overlying alluvial deposits as each could have been deposited during a separate period of fluvial aggradation and/or estuarine infilling. However, the narrow altitudinal range which most of the deposits fall within supports a single period of alluvial deposition.

High level alluvial sediments relevant to this study occur above the tidal limits in the lower Jordan Valley and underlie the sandsheets at Old Beach and Bridgewater. The geomorphic and sedimentary characteristics of these alluvial units suggest that they may be of equivalent age, and may have been deposited during the same period of alluvial and/or estuarine aggradation.

Terrace Morphology - The Jordan River, an intermittent drainage system in southeastern Tasmania, has its sources at Lake Tiberias and Lake Dulverton in the central Midlands. The river drains a catchment of some 1,300 sq. km., and flows 60 km to the Derwent estuary in the south. The Jordan follows a meandering course through a series of interconnecting, faulted valleys which consist predominantly of Triassic sediments, especially sandstones.

The river has been eroding since the late Tertiary and the channel is superimposed along its pre-basalt course in the lower reaches (McDougall, 1959). Upstream from Glenfield the Jordan has cut a narrow, meandering gorge through basalt and dolerite which widens to a broad valley near the tidal limits (Plate 1). Above the tidal limits the channel is incised into bedrock and follows a braided course between numerous pools and riffles. Individual channels are about 2-3 meters in width and most are separated by gravel point bars. The floodplain is composed mainly of organic silts up to 1 m which locally contain unweathered basalt gravel. The floodplain is parallel to the channel and decreases in thickness and elevation toward the estuary. Deposition in this portion of the river is

Plate 1. Lower Jordan Valley near Glenfield

Plate 2. High terrace level in lower Jordan Valley

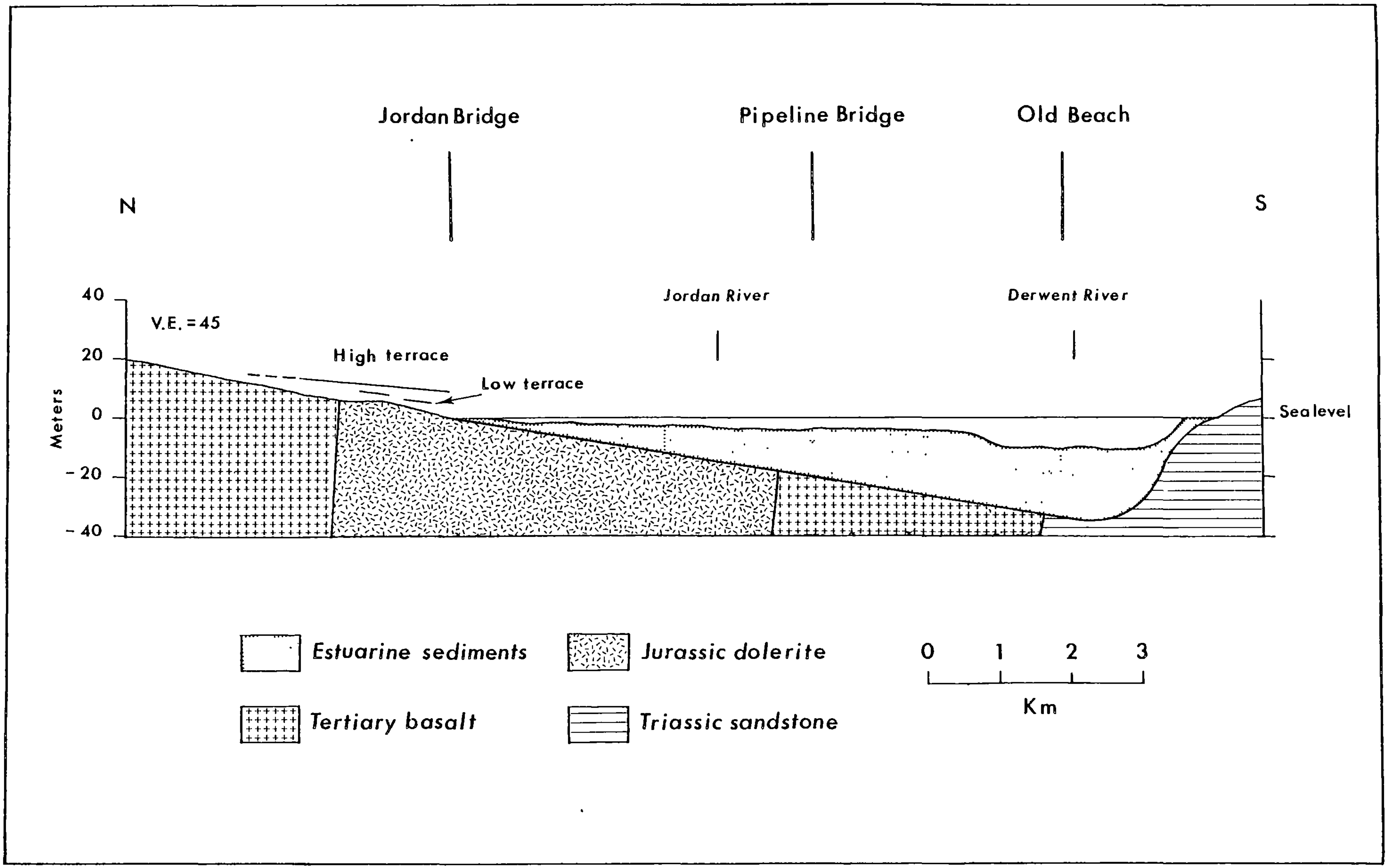


Figure 5. Longitudinal profile of the lower Jordan Valley

controlled by a low rock bar just above high tide mark,about 1 m above sealevel.

Below the rockbar the valley is drowned by the sea and occupies narrow, thalweg which joins the bed of the Derwent at Herdsman's Cove. The submerged valley is filled with fine grained estuarine sediments less than a meter below the water level. A small delta has formed at Herdsman's Cove nearly opposite the Old Beach sandsheet. This feature is trimmed on its outer margin by tidal flows generated in the main channel of the Derwent. The estimated thickness of the delta, based on the difference between bathymetric data and the projected bedrock gradient of the valley, is approximately 30 m (Fig. 5). Deposition in this area apparently results from progressive aggradation at the mouth of the Jordan during and following the Holocene sealevel rise.

Two main terrace levels border the Jordan River near Glenfield (Fig. 6). The older and higher is best preserved on the western side of the valley where it appears as a broad surface cut into the adjacent hillslope (Plate 2). The terrace is between 9-12 m above HWST at its seaward edge and is continuous for several hundred meters upstream to the entrance of the narrow gorge. The surface is not as well preserved on the eastern side and only a small remnant is present near the confluence of the Jordan and Glenfield Creek.

The terrace has been formed across the basalt-dolerite contact, but occurs neither in the narrow gorge upstream nor below the tidal limit. The terrace does not show a marked seaward gradient, but its height with respect to the present Jordan channel decreases progressively upstream. The channel crosses a series of nickpoints in this section and the gradient

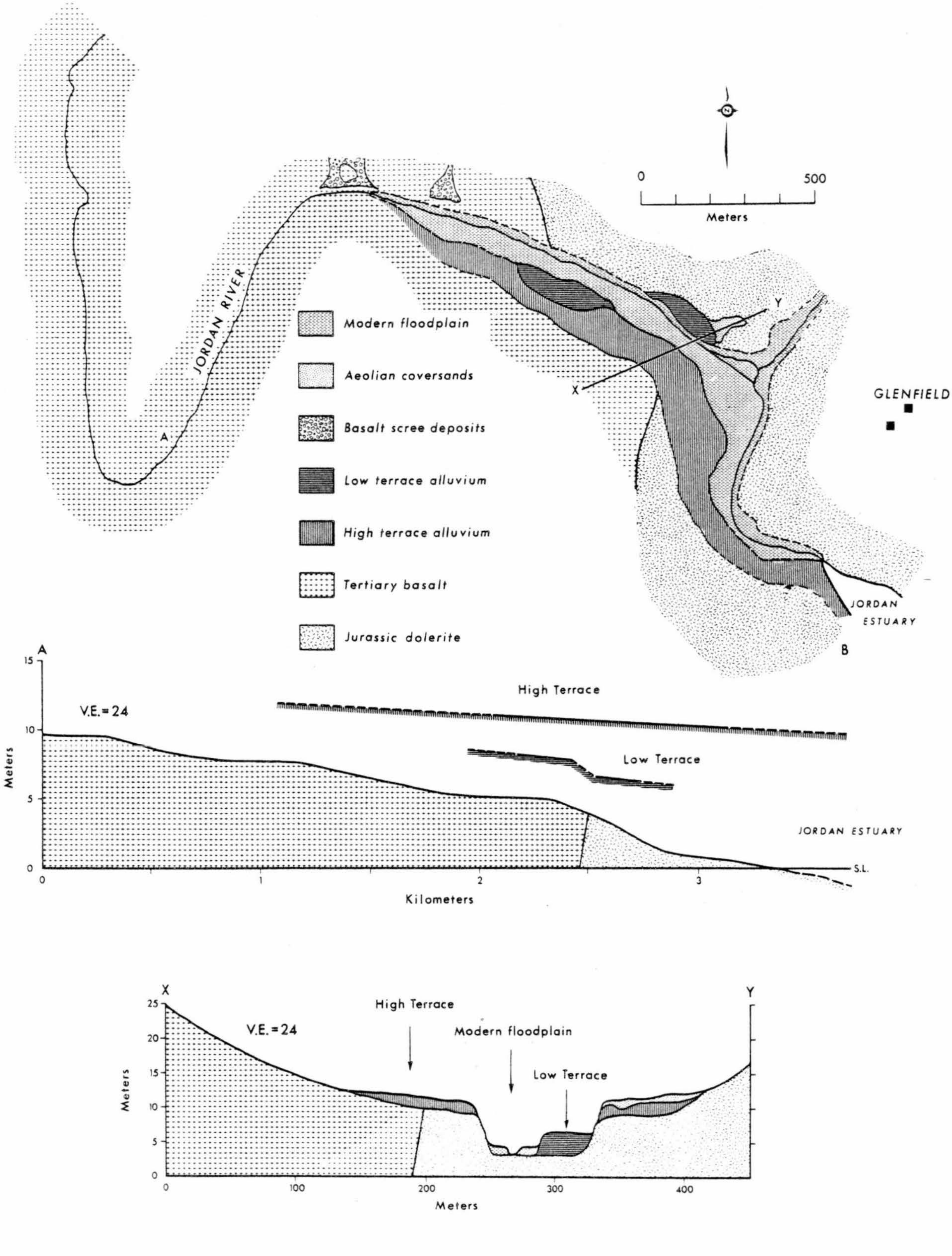


Figure 6. Terrace morphology and stratigraphy in the lower Jordan Valley

Plate 3. Old Beach peninsula and strath terrace level

Plate 4. High and low terraces in the lower Jordan Valley

of the high terrace would intersect the stream profile at some point upstream.

Fragments of an apparently similar surface are present in the adjacent Derwent Valley. This surface occurs at elevations between 9-15 m, and is present at Old Beach and remnants are discontinuously preserved for about 3 km downstream (Plate 3). The terrace is cut across basalt, dolerite and Triassic sandstone, but is not present everywhere as its preservation depends on favorable lithology and local topography.

The low terrace in the lower Jordan is 6-8 m above HWST and consists of two small remnants on either side of the main channel. These are 2-3 m above the bedrock floor and are preserved in former meander remnants protected from erosion. The projected gradient of these fragments is roughly parallel to the present channel and graded below sealevel. This level is not present along the margins of the drowned valley or in the tributary valleys adjacent to Old Beach or Bridgewater. Plate 4 depicts the relationship between the two terrace levels in the lower Jordan Valley.

<u>Stratigraphy</u> - In the lower Jordan the alluvium consists of two facies: a fine grained floodplain sediment on the eastern side of the valley, and bedload sands and gravels to the west of the present channel. The floodplain deposit consists of a heavily indurated sandy loam up to 3 m thick. The surface is irregularly truncated and the base is not exposed. Most of the deposit is massively bedded, but very thin, discontinuous dark lenses occur locally. The sand is composed mainly of very fine quartz with a few coarse grains and granules. The grains are coated with a thin film of hydrated iron oxides and clay minerals. Infrequent, sub-rounded to rounded dolerite cobbles occur throughout the deposit.

On the western side of the valley alluvium consists mainly of gravels in a medium to fine sand to silt matrix and is up to 2 m thick. The deposit directly overlies the rock surface and increases in thickness toward the mouth of the river. The gravel is sub-rounded to rounded, consists of cobbles and a few pebbles which make up between 15-20% of the deposit, and consists mainly of quartz or quartzite with lesser amounts of strongly weathered basalt, dolerite and sandstone.

At Old Beach the 9-15 m strath terrace is overlain by sandy alluvium up to 2 m thick which locally contains thin beds of pebbly gravel. The deposit varies from coarse to medium quartz sand at the base to a fine loam at the top. Sub-rounded pebbles and granules occur throughout, but most are concentrated into thin tabular beds near the base of the deposit. The alluvium is truncated on both sides of the Old Beach Peninsula and does not occur in the adjacent tributaries. Thin remnants of similar pebbly sands and silts mantle the strath surface south of Old Beach, and are continuous for some distance downstream along the margin of the Derwent.

At Bridgewater a small remnant of alluvial sands and gravels is exposed along the margins of the estuary (Plate 5). The deposit is between 2-3 m in thickness and overlies a low dolerite strath surface up to 50 cm above HWST. The sediments are exposed for about 100 m and extend several meters inland.

The deposit consists mainly of coarse to medium sand with embedded pebbles and gravel resting directly on dolerite. The gravel is sub-rounded to rounded quartz, quartzite and dolerite and makes up approximately 30-50% of the deposit. The alluvium is massively bedded and irregularly truncated by dolerite colluvium.

Plate 5. High level alluvial gravels at Bridgewater

The high level alluvial sediments at Bridgewater and Old Beach are mainly derived from the Derwent catchment. The Old Beach deposit is probably derived from sediment transported from the Jordan and the tributary valley east of the site.

The low terrace sediments of the lower Jordan Valley consist of alluvial sands and silts 3 m thick. The basal 140-150+ cm consists of well sorted, medium to fine quartz sands deposited directly on rock. The sands grade upward into very fine sandy silts which form the upper 120 cm of the deposit. These sediments are massively bedded and contain very little gravel.

Pedogenesis - The high alluvial sediments have been strongly weathered and show relatively mature soil profiles. The profiles have been truncated after formation and the surface horizons are missing.

On the high terrace east of the Jordan the upper 60-80 cm of the alluvium shows angular blocky peds with continuous cutans of clay and iron oxides. This portion of the soil is red to reddish yellow, and is interpreted as the B horizon of the profile on the basis of its color and structural development.

The C horizon is lighter in color with a single grained structure. There is no evidence of mottling in either horizon and the profile does not contain free carbonate. All of the basalt, dolerite and sandstone gravel contained in the alluvium are weathered and show rinds up to 10 mm thick.

A similar profile is developed on the high terrace alluvium at Old Beach, although the B horizon is darker and only between 20 to 50 cm thick. This horizon is organized into angular blocky peds with stress cutans on the interfaces. The lower boundary of the B horizon is gradational and the C horizon has a single grained structure. Free carbonate occurs in the C horizon as soft, weakly adhesive vertical sheets, but does not cement the matrix.

The gravels at Bridgewater are also strongly weathered, but the deposit is not organized into a distinct soil profile. The dolerite and basalt gravel shows weathering rinds up to 2 cm in thickness, and are coated with a thin film of cutanic clay and iron oxides.

The sediments of the low terrace are less strongly weathered than those of the high terrace. The upper 20-30 cm of the deposit is dark grey, single grained, and probably represents a disturbed A horizon.

The B horizon is oxidized and organized into weakly developed, very coarse subangular blocky peds with no evidence of cutans. The C horizon has a single grained structure,and contains soft, weakly adhesive free carbonate consisting of small nodules, tubules and thin vertical sheets. The presence of the carbonate indicates locally impeded drainage conditions near the bedrock channel of the Jordan.

Slope Deposits - Several small scree deposits locally occur along the margins of the lower Jordan Valley (Fig. 6). These extend as small aprons of block debris from steep, south-facing slopes (Plate 6). These deposits consist of angular cobbles and boulders derived from the jointed basalt cliffs upslope. Most of the screes have smooth concave slopes, although a few have irregular, hummocky surfaces. The debris is usually less than a meter in thickness and is unstratified.

The screes have little or no matrix. Most blocks have developed weak weathering rinds between 1-2 mm in thickness. They are stable in the

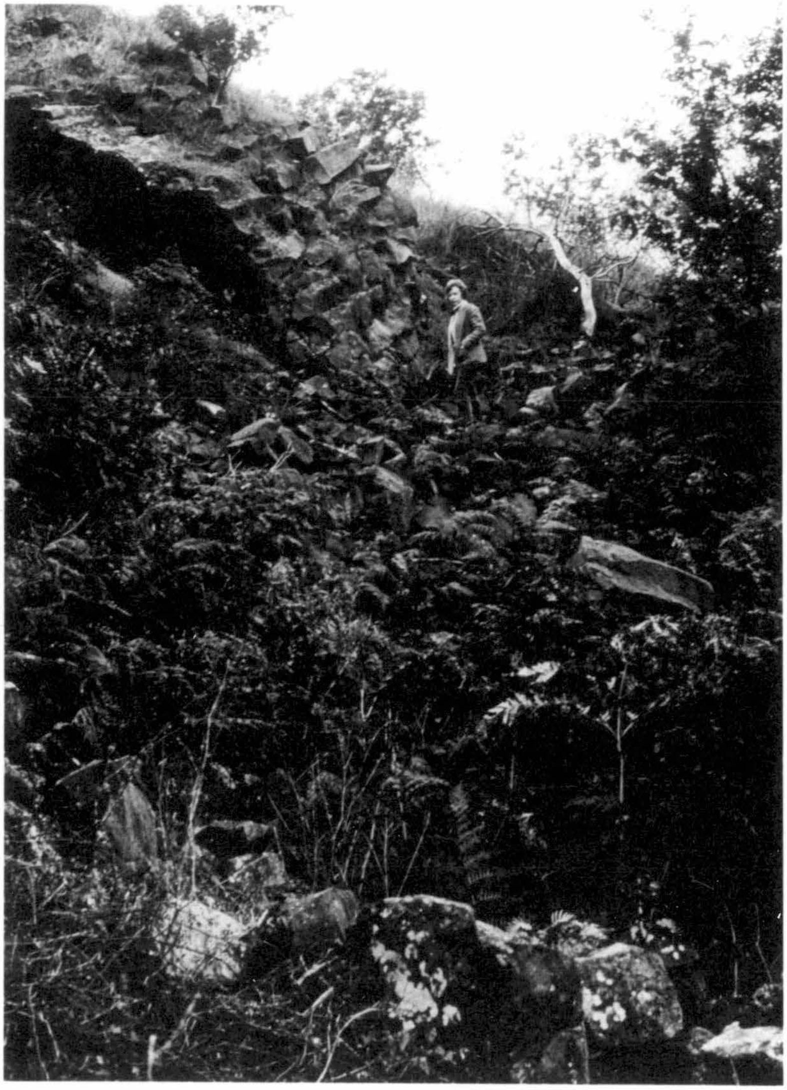


Plate 6. Basalt scree deposits in the lower Jordan Valley

present environment and the rock fragments are sparsely covered with lichens. There are no freshly fractured surfaces on the adjacent cliffs and the debris appears to have been produced by processes that no longer operate at this locality. The angularity of the rubble and its position immediately downslope from the jointed basalt suggest that the screes may have formed through the action of frost wedging in a colder environment.

II. AEOLIAN SANDSHEETS

A. Glenfield

Introduction - The Glenfield sandsheet is about 18 km north of Hobart on the farm of Mr. G. Marshall. The deposit has an elongate shape and is located some 200 m east of the Jordan Valley (Fig. 7, Plate 7). The present form of the sandsheet is a low hummocky dune (Plate 8), but much of the original surface has been disturbed by quarrying and grazing.

The sandsheet overlies a high angle contact between the Triassic sediments and the dolerite. The contact zone dips between 20° - 60° NE and strikes in a northwesterly direction. Triassic sediments, consisting of gently dipping fissile siltstones, fine grained sandstones, and thin coal measures, crop out east and southeast of the contact, and the dolerite is exposed to the west and southwest. Near the contact zone, thermal alteration has modified both rock types and produced quartzites and cherty hornfels.

Stratigraphy - The sandsheet consists of four main aeolian units including a basal loamy sand unconformably overlain by three later sand deposits (Fig 8). The type section is in a north to south oriented trench near the extreme western edge of the site (Plate 9).

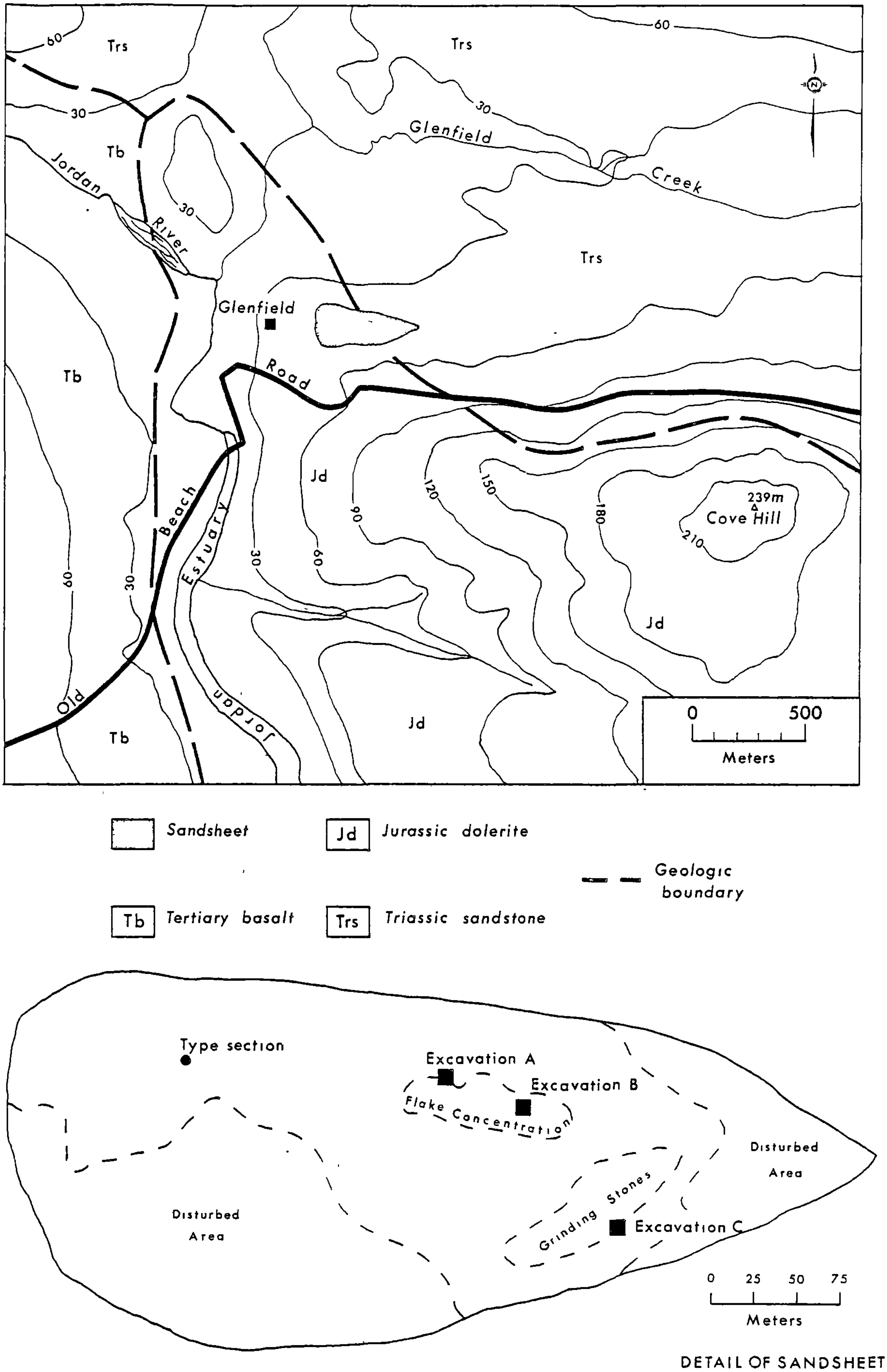


Figure 7. Location map of the Glenfield sandsheet

Plate 7. The Glenfield sandsheet

Plate 8. The Glenfield sandsheet showing hummocky topography

The sandsheet overlies a complex series of slope deposits which are locally up to 4 m thick. These units increase in thickness downslope, and are composed of a number of laterally continuous and discontinuous units. The sequence consists mainly of weathered rock and clastic debris locally derived from both the Triassic sediments and the dolerite. Very thin, discontinuous lenses of fine quartz sand are also interbedded with the slope deposits near the eastern margin of the site. These were probably deposited during an earlier phase of aeolian activity, but due to poor exposure their lateral extent and precise origin are unknown. The beds are unweathered and appear to have been rapidly buried by the overlying slope deposits.

Correlation of the slope deposits and interbedded aeolian lenses is difficult due to the discontinuous nature of the units and sudden facies changes. The entire sequence indicates that multiple phases of slope and aeolian deposition occurred at the site prior to the formation of the main sandsheet. Interbedding of the aeolian sand with the colluvium indicates local hillslope instability synchronous with conditions favorable to aeolian erosion near the site.

The textural and soil profile characteristics for the main aeolian units at Glenfield are given in Table 4. The data for the basal aeolian unit is from the type section. The data for the upper sand units are derived from the section exposed at Excavation Site A as the units are thicker at this location than at the type section.

Unit 1, a moderately consolidated, loamy sand between 20 to 130 cm thick, is a tabular wedge of sand which is thickest on the western margin of the site. The gross lithology varies considerably, and in

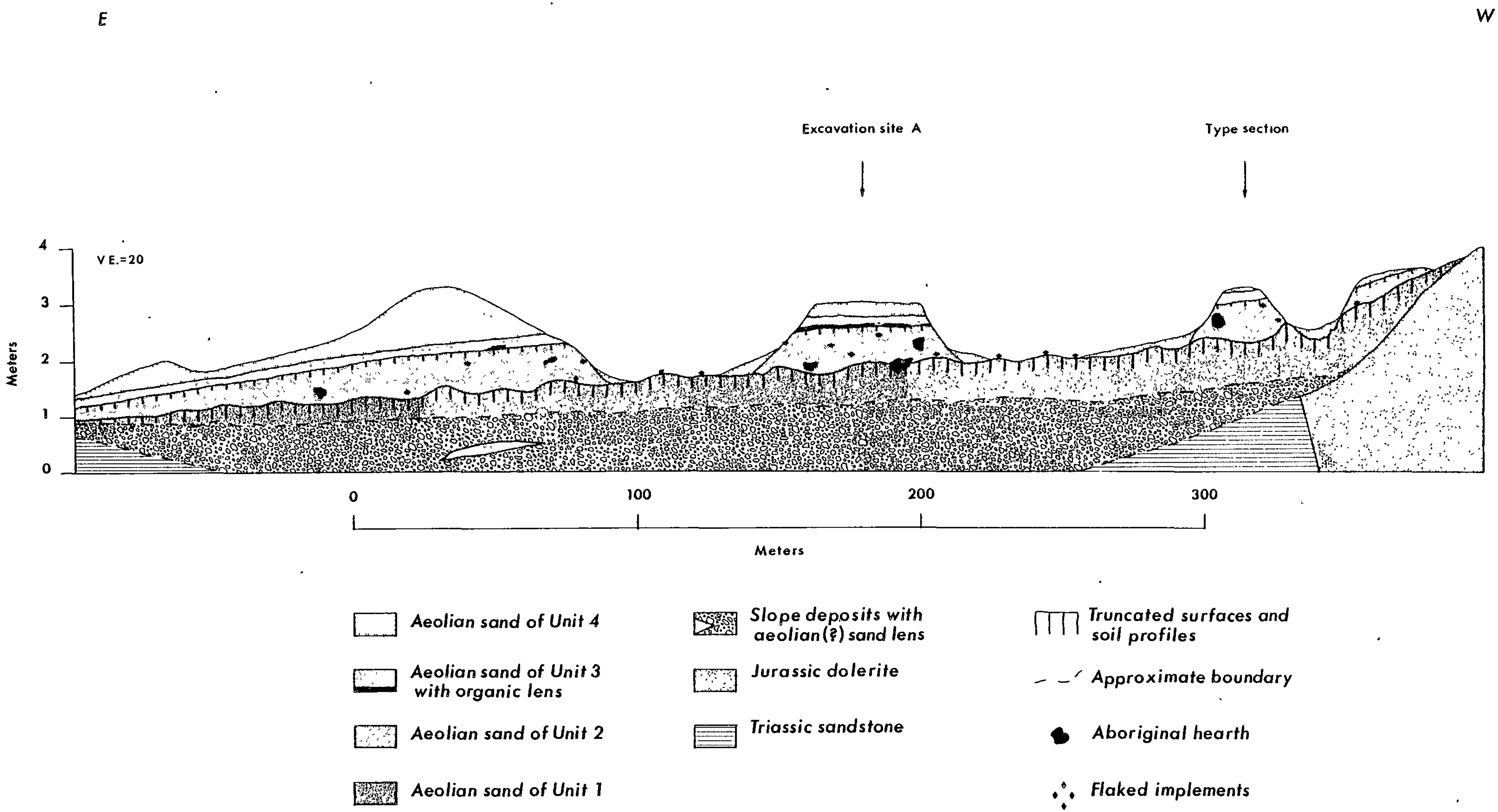


Figure 8. Cross-section of the Glenfield sandsheet

Plate 9. Type section of the Glenfield sandsheet

downslope positions,the unit is a mottled sandy clay which contains small carbonate nodules and dolerite fragments. This facies results from the mixing of sand with colluvial material by slopewash. Upslope, the unit is sandier and redder due to excessive drainage and increased oxidation.

At the type section Unit 1 is 110 cm thick and overlies sandy Triassic slope material that rests directly on sandstone. The aeolian sediments are massively bedded, poorly sorted and are composed mainly of fine quartz sand and clay with little or no silt. Clay is most abundant in the upper 15 cm and decreases sharply with depth. Mean grain size and sorting show a positive correlation with clay content and an inverse relationship with depth. However, the sand fraction is well sorted throughout and has a modal range of between 2.5 to 3.0 $\emptyset$.

Unit 1 is irregularly truncated and overlain by the massively bedded sands of *Unit 2*. The sharp contact between the units resulted from a subsequent phase of aeolian activity as the surface of Unit 1 locally shows evidence of wind scour. Unit 2 is thickest near the center of the site and upslope. To the west it overlies the basal sandsheet, but to the east, the sands directly overlie slope deposits derived from the sandstone. The original form of the dune cannot be reconstructed entirely due to the extensive European disturbance and modification of the site. However, Unit 2 accumulated as a thin wedge of sand and its known lateral variations suggest a local deflation source to the west.

Unit 2 is weakly consolidated and consists of fine sand up to 120 cm thick. At the type section it is about 40 cm thick and consists of well sorted quartz with subordinate amounts of feldspar and dark minerals. Locally, the unit shows weakly developed, subhorizontal bedding planes, but for the most part it is massively bedded throughout.

At the excavation site the sand is well sorted with a modal diameter between 2.5-3.0 Ø and the unit contains very little silt or clay fraction. The skewness value indicates a nearly symmetrical grain-size distribution with the sand mode being better sorted than the fines. This distribution suggests that the deposit probably represents a saltation load derived from a well sorted source of sand.

The textural parameters of Unit 2 are well within the range of those observed in modern aeolian sands (Folk, 1965). Unit 2 is somewhat coarser than the underlying sandsheet and displays much better sorting. This contrast is due to the greater proportion of clay-sized material in the basal sandsheet as compared with Unit 2. However, the modal grain-size of the sand fraction in both deposits is nearly identical. This relationship indicates that either both units were derived from alluvial sources of similar nature, or that Unit 2 is derived from the aeolian reworking of the underlying Unit 1. Consideration of this relationship will be more fully discussed in Chapter 6.

Two radiocarbon dates were obtained from charcoal associated with Unit 2. The charcoal was taken from Aboriginal hearths exposed in an excavation pit located approximately 50 m east of the type section (Plate12). A basal date of 2055 ± 120 BP (SUA-305) was also obtained from a hearth which was intrusive into Unit 1. A second date of 1245 ± 80 BP (SUA-304) was obtained from a second hearth located between 15-20 cm below the surface of Unit 2. These dates nearly bracket the period of deposition and the older date provides a minimum age for the truncation of Unit 1 at this locality. Also, the presence of hearths demonstrates that the deposition of Unit 2 was synchronous with Aboriginal occupation of the site.

TABLE 4

TEXTURAL AND SOIL PROFILE DATA FOR THE GLENFIELD SANDSHEET

A. COVERSAND UNITS AT EXCAVATION SITE A

DEPTH CM	UNIT	STRUCTURE AND REACTION	COLOR	TEXTURE	SAND	SILT + CLAY	M_z	σ_1	S_k
0-10	4	Single grained weakly acid	10 YR 7/3	Sand	98.71	1.29	2.46	0.47	0.25
30-40					99.10	0.90	2.41	0.44	0.21
45-50	3	Single grained weakly acid	10 YR 3/2	Sand	98.31	1.69	2.46	0.49	0.22
55-60			10 YR 3/2		98.75	1.25	2.43	0.48	0.21
75-80		Single grained weakly acid			98.68	1.32	2.47	0.48	0.19
95-100	2			Sand	99.06	0.94	2.44	0.46	0.23
115-120			10 YR 7/4		98.30	1.70	2.59	0.50	0.19

B. UNIT 1 AT THE TYPE SECTION[1]

DEPTH CM	SOIL HORIZON	STRUCTURE AND REACTION	COLOR	TEXTURE	SAND %	SILT %	CLAY %	M_z	σ_1	E Fe_2O_3	T Fe_2O_3	T Al_2O_3	T Fe_2O_3 + T Al_2O_3	CLAY MINERALS M	I	I/M	K	Q
10-15	B	Moderately developed, very coarse, sub-angular blocky peds;	7.5 YR 5/8	loamy sand	83.56	1.54	14.88	3.80	2.07	0.52	1.83	6.21	8.04	xxxx	x	?	xx	xxx
30-35					91.84	0.81	7.30	2.88	1.67	0.44	1.80	5.47	7.31					
50-55		Neutral to weakly acid.		sand	92.18	1.11	6.70	2.89	1.60	0.41	1.93	5.54	7.37	xxx	x	x	x	xxx
70-75	C				92.63	0.51	6.97	2.70	1.67	0.34	1.79	6.67	8.46					
100-105		Single grained; weakly alkaline	10 YR 6/8	sand	91.88	0.72	7.39	2.89	1.69	0.45	1.87	5.52	6.94	xx	x	x	–	

1. S_k not derivable due to excessive clay in the deposit.

The surface of Unit 2 is locally overlain by a thin subhorizontal lens of organic fine sand between 5-10 cm in thickness. The bed is weakly cemented by organic matter and locally contains large fragments of charcoal. The sub-unit is best developed in the west-central portion of the site and is generally absent from other localities. The textural parameters of these sands are nearly identical to those of Unit 2, although the organic content is much higher.

A radiocarbon date of 210 $\pm$ 80 BP (SUA-303) was obtained from charcoal associated with the organic sand. The sample was taken from a hearth on the surface of Unit 2 and buried by the sands of *Unit 3* (Plate 10). The hearth contained at least five small logs in juxtaposition with a shallow bulb of ash in the center. The underlying sands are indurated and appear to have been baked. This hearth and the associated organic fine sand lens provide unequivocal proof that Units 2 and 3 are separate stratigraphic entities,and that they are not horizons of a monogenetic soil profile. The radiocarbon date provides a minimum age for the end of Unit 2 deposition and a maximum age for the deposition of Unit 3. These dates clearly indicate that the deposition of Unit 2 occurred prior to European occupation of Tasmania,while deposition of the succeeding two units post-date this event.

The surface of Unit 2 is truncated and is unconformably overlain by *Unit 3* which consists of 5-30 cm of fine sand. The contact between the two units is sharp and horizontal except where disturbed by roots and animal burrows.

Unit 3 is thickest in upslope positions and in the west-central portion of the site. The sands were not observed in contact with the

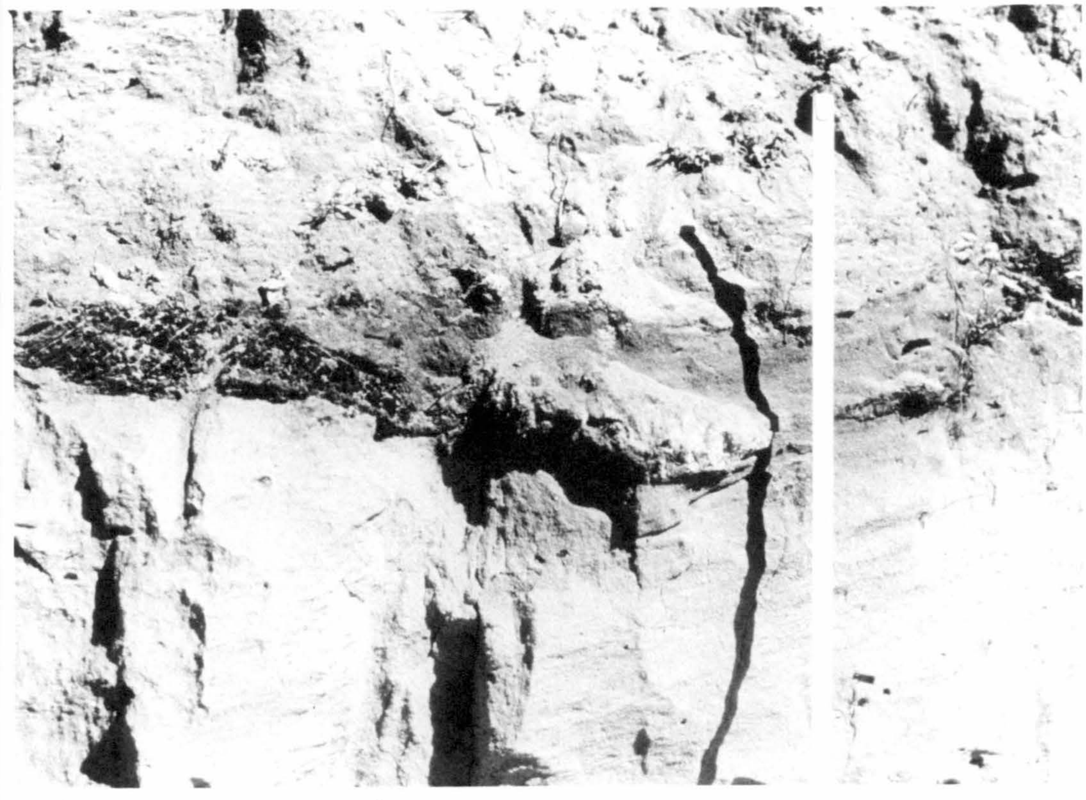


Plate 10. Aboriginal hearth separating Units 2 and 3 at Glenfield (210 ± 80 BP)

Plate 11. Fencepost buried by aeolian sands of Unit 4 at Glenfield

basal sandsheet and appear to only overlie Unit 2. The sands are massively bedded and consists predominantly of well sorted, fine quartz with a small amount of silt and clay-sized material.

The textural parameters of the sands of Unit 3 are essentially similar to those of Unit 2 and are well within the range of modern aeolian sands. The close textural similarity between these two units suggest a strong genetic relationship, and Unit 3 is most likely derived from the aeolian reworking of the underlying Unit 2 by westerly winds.

The surface of Unit 3 is also truncated and is overlain by the massive, aeolian fine sands of *Unit 4* which are up to 250+ cm thick. The lower contact with Unit 3 is sharp and horizontal to locally undulating.

The depth of Unit 4 varies considerably, but the sands are generally thickest to the east where the unit has locally buried fence posts (Plate 11). The sands occur over most of the site and locally overlie the basal sandsheet where it is exposed in heavily eroded areas. Except for this association, Unit 4 was only found overlying the surface of Unit 3 and was never observed in contact with Unit 2. Very thin bedded, subhorizontal lenses of fine sand occur locally in Unit 4, especially to the east where the sands are thickest. These thin beds indicate some periodicity in aeolian deposition and the sub-units are probably related to cycles of accelerated erosion resulting from European-disturbance of the site.

The sands of Unit 4 are texturally similar to those which compose Units 2 and 3, and have sedimentary characteristics of modern aeolian sands. The close textural relationship between the units suggest that Unit 4 is derived from the aeolian erosion of the underlying sand units in response to European disturbance of the site. The form and lateral orientation of all the upper sand units indicate that westerly winds were responsible for their deposition.

Pedogenesis - *Unit 1* is weathered and shows evidence of moderate pedologic organization. The unconformity at the top of the deposit and absence of an A horizon indicates that the surface was eroded prior to burial by Unit 2.

The upper 20-25 cm of the profile is brown and is organized into subangular blocky peds with weakly developed and discontinuous cutans on the ped surfaces. This portion of the profile is considered to be the B horizon, and at the type section it contains no evidence of free carbonates. The lower boundary of the B horizon is gradational and the C horizon has a single grained structure throughout.

There is considerable profile variation over the site, apparently due to local drainage conditions and the close proximity of the dolerite and its slope derivatives. In downslope positions, the profile is gleyed and irregularly mottled and the reaction is strongly alkaline. The clay content of both horizons tends to increase downslope and free carbonate occurs where drainage is impeded. Upslope, the profile more closely resembles that of the type section, but the soil horizons are somewhat redder due to strong oxidation under conditions of excessive drainage.

The geochemical and clay mineral data for Unit 1 shows little variation in the profile. Extractable iron is higher in the B horizon than in the C, but the other oxides show little or no systematic variation with depth. The clay mineralogy also shows little variation with depth, but montmorillonite and kaolinite are relatively more abundant in the B horizon than the C.

The abundance of montmorillonite especially in the B horizon, suggests minimal hydrolysis of feldspar and mafic minerals with the partial release of iron. Given the porosity of the sands, weathering most likely occurred in a relatively acid, leaching environment. The presence of small amounts of kaolinite in the B horizon may indicate the partial breakdown of montmorillonite here. Illite may either be a transitional stage of this reaction or it may be in the form of clay-sized muscovite or biotite.

Given the lack of profile differentiation on the basis of these parameters, only the increased clay content in the B horizon seems pedologically significant. Chemically, the profile appears weakly developed, but a moderate degree of soil formation is indicated by the macroscopic evidence, especially ped development and horizon color. The higher clay content in the B horizon could be a primary depositional feature, but the weakly developed cutans indicate that some illuvial and/or *in situ* formation of clay occurred in association with weathering of less stable mineral constituents.

A very weak soil is developed on *Unit 2*, as indicated by the light reddish coloration in the upper 5-10 cm of the unit, but the profile shows no evidence of textural differentiation. The redder hue near the top of the deposit suggests weak oxidation of iron compounds. As the upper surface of the deposit is truncated, the reddish coloration probably represents a very weakly developed B horizon on the parent sands during groundsurface stability following deposition. The sands of *Unit 3* show little or no evidence of profile development and the color is uniformly very dark greyish brown throughout. There is also little or no evidence of distinct soil profile on the sands of Unit 4. The subhorizontal bedding planes appear to have been weakly oxidized between successive periods of aeolian erosion at the site.

As the geochemical and clay mineral data for Unit 1 did not provide significant variations within the profile, it seemed unlikely that the much weaker soils developed in the upper sands would produce meaningful data of this type without a much larger program of analysis. The Unit 1 profile is the best developed, and provides important evidence to support a relatively long period of stability and weathering prior to truncation and burial by Unit 2. This profile most likely represents the top of a truncated late glacial or Holocene soil disturbed after 2,000 BP. The weak soils on the upper aeolian units probably formed in either decades, or at best, during centuries of weathering and surface stability.

Archaeology - The unconformable surface of Unit 1 is apparently the base of Aboriginal occupation at this site. The basal unit locally contains finely divided charcoal, but conclusive evidence of occupation has not been found.

Most of the cultural material occurs in association with Unit 2, and this deposit contains numerous hearths, flaked implements and grinding stones. The unit has been extensively modified by European land use and few undisturbed sections remain. Much of the cultural evidence occurs on the surface of Unit 1, either dropped by the Aboriginals or lowered to this surface as Unit 2 was progressively eroded. This type of evidence is not very suitable for establishing typological associations with other sites as the stratigraphy cannot be controlled. In addition, the Glenfield sandsheet, as with most exposed sites in Tasmania, has been a site visited by amateur collectors since European occupation.

Three stratigraphically controlled pits were excavated in relatively undisturbed portions of the site. These were located near the base of the slope, the center of the site and near the upslope margin of the sandsheet (Fig. 7). The downslope excavation site yielded the most abundant material and the three radiocarbon dates were obtained from hearths at this locality (Fig. 9 , Plate 12).

The distribution of hearths in Unit 2 presented a complex micro-stratigraphic problem. Most consist of amorphous concentrations of loose charcoal fragments and burned logs in a weakly cemented matrix of black, carbonaceous sand. Many hearths are intrusive into older ones and the boundaries are difficult to follow. The hearths are not associated with firestones and none contain identifiable bone material. However, one hearth associated with Unit 2 did contain shells of *Xenostrobus securis*, an edible estuarine mussel.

Unit 2 contains numerous small flakes and a few broken grinding stones (Fig. 10). The relative density of lithic material is greatest in the upper 20-25 cm of the deposit and decreases uniformly with depth. The implements are generally found near hearths,and consist mainly of simple flakes showing little secondary retouch, a few small backed blades and scrapers.

The majority of the flaked implements are composed of cherty hornfels with a few pieces of quartzite and silicified breccia. The fragments of grinding stones were identified on the basis of planed rock surfaces and all were composed of dolerite. Fragments of red ochre, probably obtained from the basalt, are common throughout the deposit.

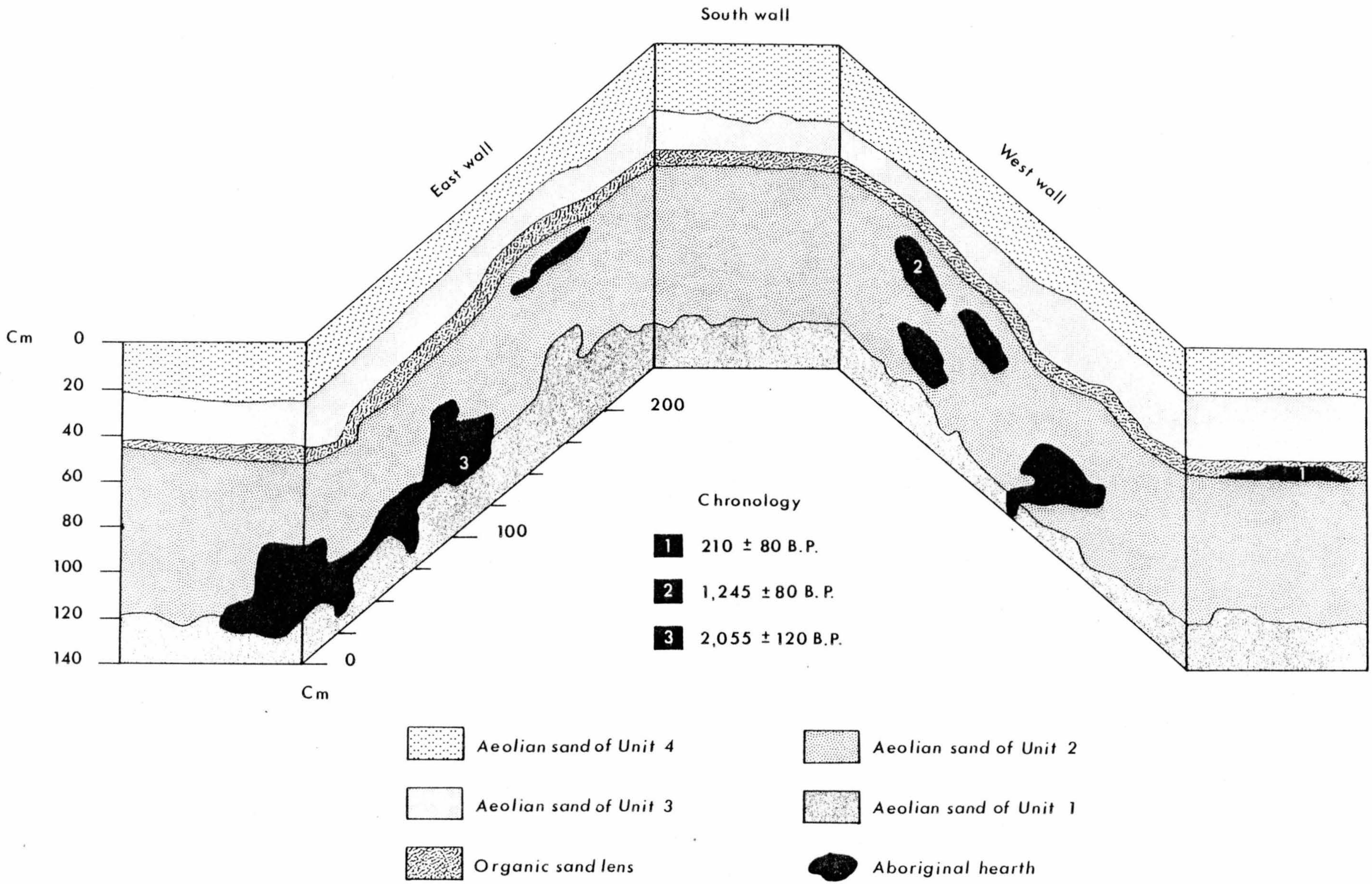


Figure 9. Stratigraphy and archeological relations of Excavation Site A of Glenfield

Plate 12. Excavation Site A at Glenfield

Plate 13. Lumps of clay in organic sand lens at Glenfield

Concentrations of small flakes and chips are locally present on the exposed surface of the basal sandsheet. Lithic fragments are scattered over small areas generally near the downslope margins of the site and may indicate flaking floors. In upslope locations numerous grinding stone fragments litter the exposed surface of the basal sandsheet, but flake scatters are relatively uncommon. The surface distribution of grinding stones and flaking floors probably indicates specialized activity areas during occupation. Although the stratigraphic position of these implements cannot be determined, they are probably associated with the period of Unit 2 occupation.

The organic sand lens at the surface of Unit 2 contains numerous small flakes and other lithic fragments. The moderate induration of the unit is probably due to compaction and cementation by humic material. This surface has a hummocky microtopography and locally contains circular depressions and low irregular ridges. One depression contained small pieces of dark brown, dolerite clay which had been molded into lumps, one of which was approximately 3 cm in diameter (Plate 13). The deposit also contains numerous badly decomposed twigs and a few unidentifiable seeds.

Flakes, implements, or other evidence of Aboriginal occupation do not occur in either Units 3 or 4. Their absence suggests abandonment of the site prior to the deposition of these units. Unit 3 contains relatively high percentages of *Eucalyptus*, Gramineae, and *Taraxacum* pollen. *Eucalyptus* and Gramineae pollen are typical components of the modern pollen rain in the area and these plants were probably established near the site throughout most of the Holocene. The most significant feature of the pollen sample is the high proportion of *Taraxacum*, an introduced European

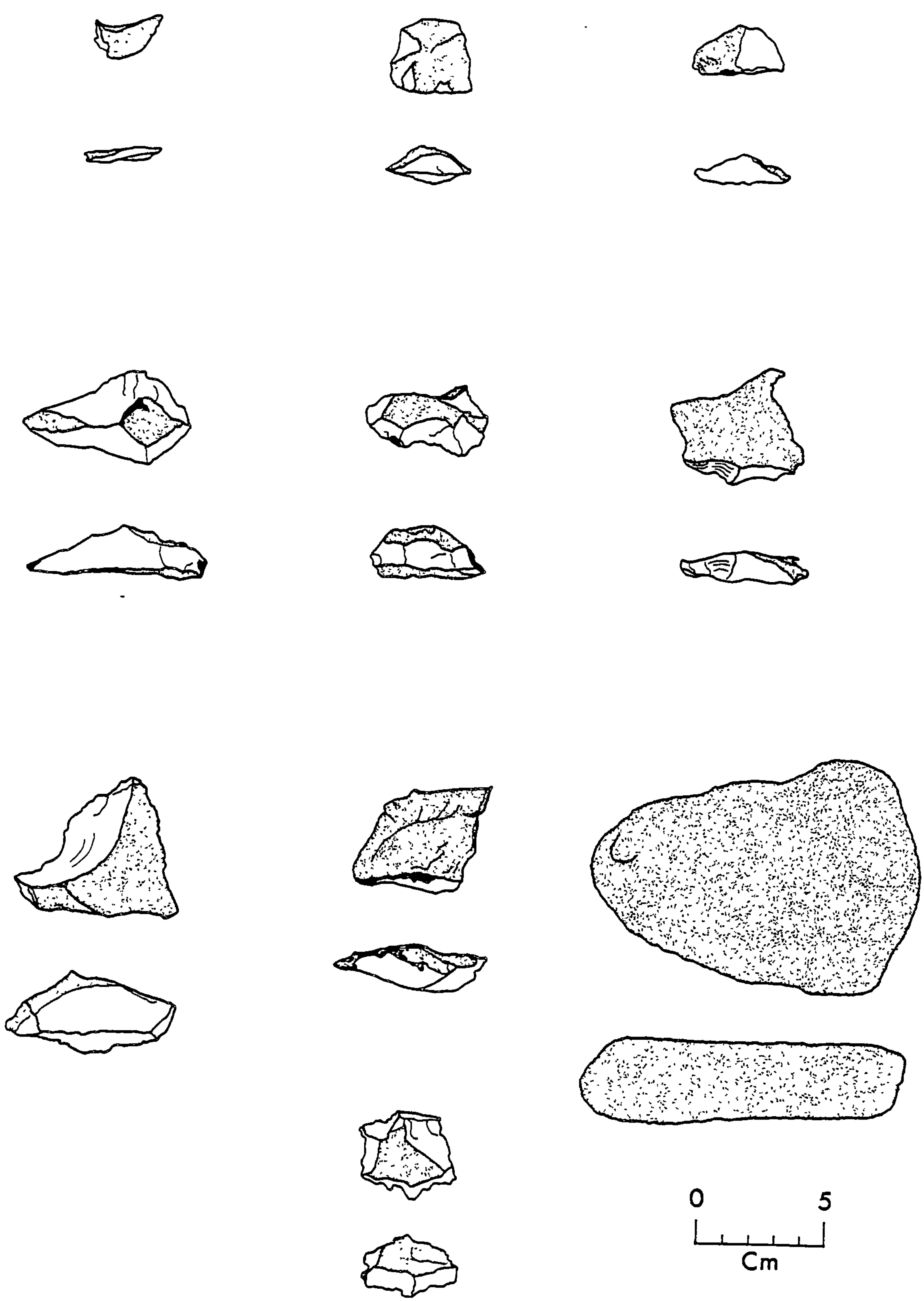


Figure 10. Selection of Aboriginal implements recovered from Unit 2 at Glenfield

composite. Its presence in Unit 3 offers independent evidence that these sands and those of Unit 4 were deposited after European occupation.

B. Old Beach

Introduction - The Old Beach peninsula lies directly southeast of Herdsman's Cove near the confluence of the Jordan River with the Derwent Estuary (Fig. 11). The peninsula is part of a Tertiary basalt flow lying between an area of Triassic sandstones and siltstones. The sandsheet occupies a narrow portion of the peninsula and its long axis is aligned roughly WNW. The aeolian sediments are deposited on the eroded surface of the basalt strath terrace and extend inland for about 0.8 km. (Fig. 12).

The site is extensively disturbed, but in relatively undisturbed areas, the sandsheet preserves a low, flat surface morphology with little or no dune development. The deposit is truncated at the edges of the peninsula and does not occur in the adjacent valleys.

Stratigraphy - The type section for the sandsheet is located some 300 m east of the estuary, exposed in a north-south drainage ditch (Fig. 13, Plate 14). The sandsheet consists of four aeolian units which include a basal deposit unconformably overlain by three later sand units.

The basal aeolian deposit, *Unit 1*, unconformably overlies the truncated surface of the high level alluvial sediments. The contact between the two is sharp and locally undulating and there is little or no mixing of the deposits at the interface.

Unit 1, up to 120 cm thick, is a relatively thin wedge of sand covering most of the peninsula. As far as can be determined the sand increases in thickness with distance from the estuary to the middle of the

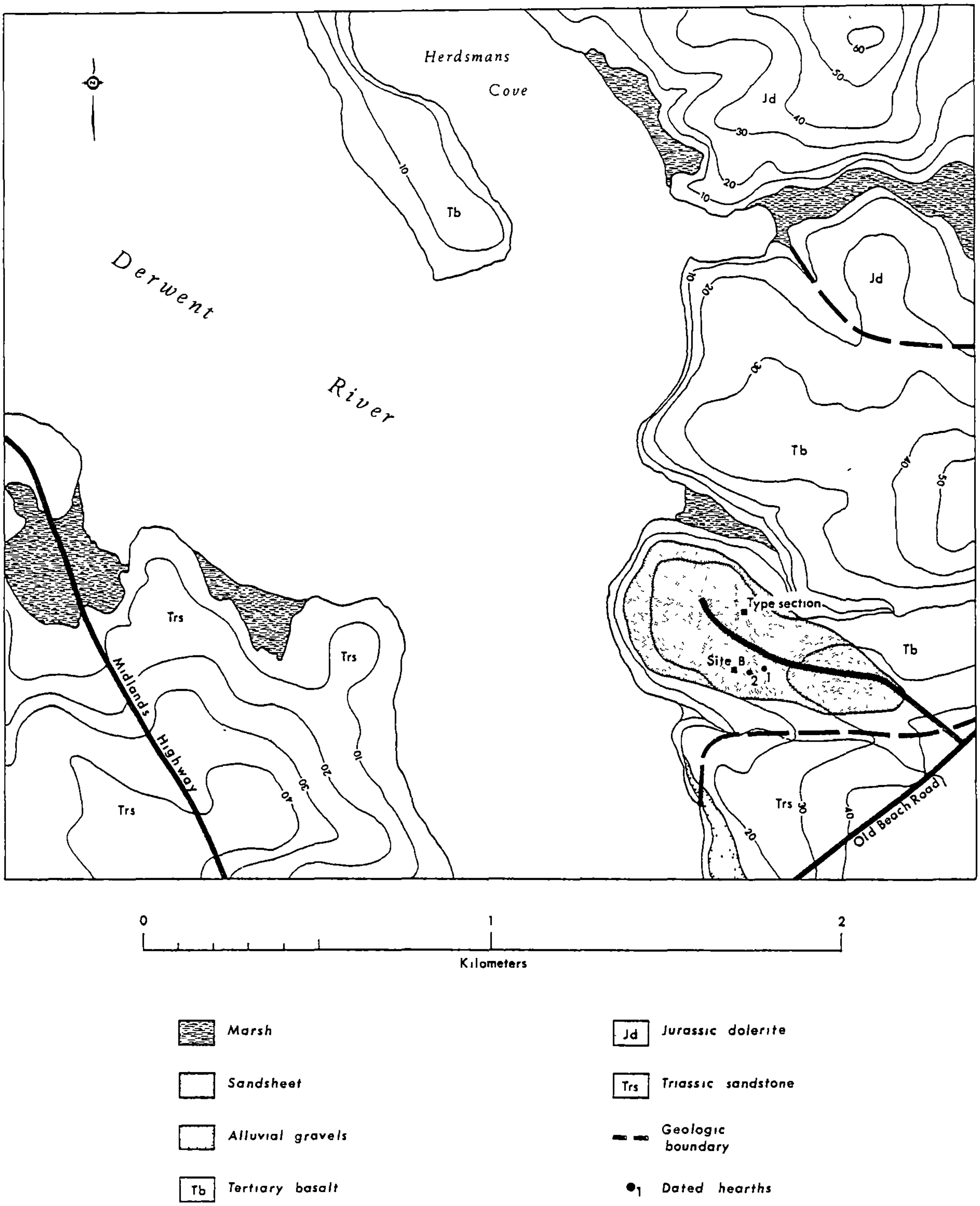


Figure 11. Location map of the Old Beach sandsheet

Plate 14. Type section of the Old Beach sandsheet

Plate 15. Old Beach sandsheet showing hummocky topography

peninsula and then thins eastward. The unit also increases in thickness to the south and southeast. Where exposed, the surface is heavily impacted and shows a low, hummocky microtopography (Plate 15). In a few heavily disturbed areas the basal sandsheet has been completely eroded and the underlying alluvial sediments are exposed at the surface.

At the type section Unit 1 is about 60 cm thick and consists of a moderately consolidated, sandy clay loam. The unit shows considerable textural variation across the site and is somewhat coarser near the margins of the estuary and to the extreme southeast. At all locations the sediments are massively bedded and show no evidence of internal discontinuities.

The textural and soil profile characteristics for the basal sandsheet (Unit 1) at the type section are given in Table 5. The sediments are not well sorted and contain significant proportions of silt and clay. The well sorted, fine sand fraction consists primarily of quartz with smaller proportions of feldspars and dark mineral grains. Because of the excess of silt and clay in the sediments, the texture parameters are not derivable. However, the amount of clay sized material is greatest in the upper and lower portion of the deposit. Silt is most abundant in the upper 25 cm of the deposit and decreases sharply with depth.

The apparent poor sorting in the deposit due to abundance of fines suggests that pedogenic processes may have significantly altered the original parent material. As will be seen, the deposit is moderately weathered, but the abundance and distribution of silt suggests that some portion of this material may have been transported by wind during the period of aeolian activity.

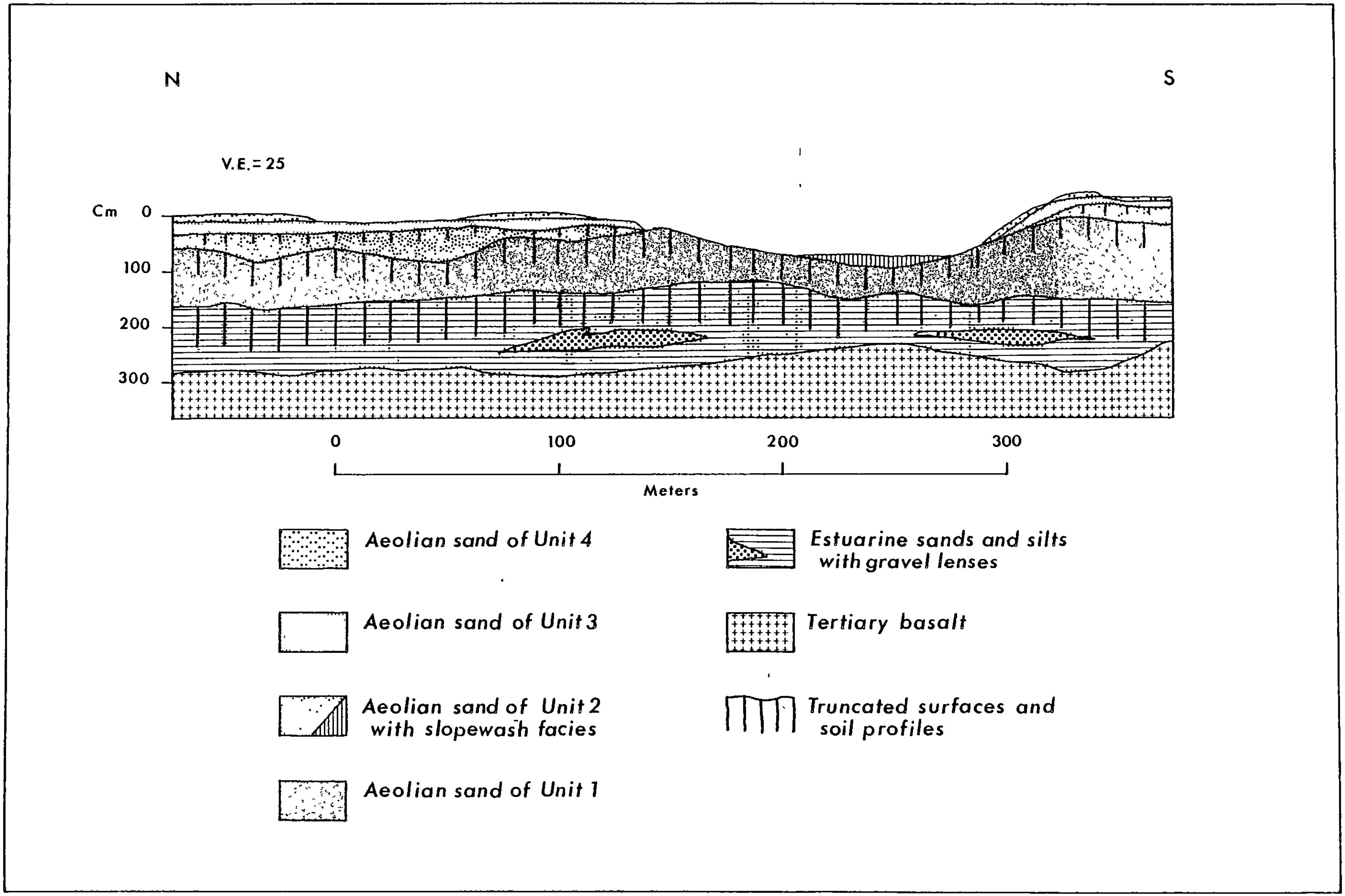


Figure 12. Cross-section of the Old Beach sandsheet

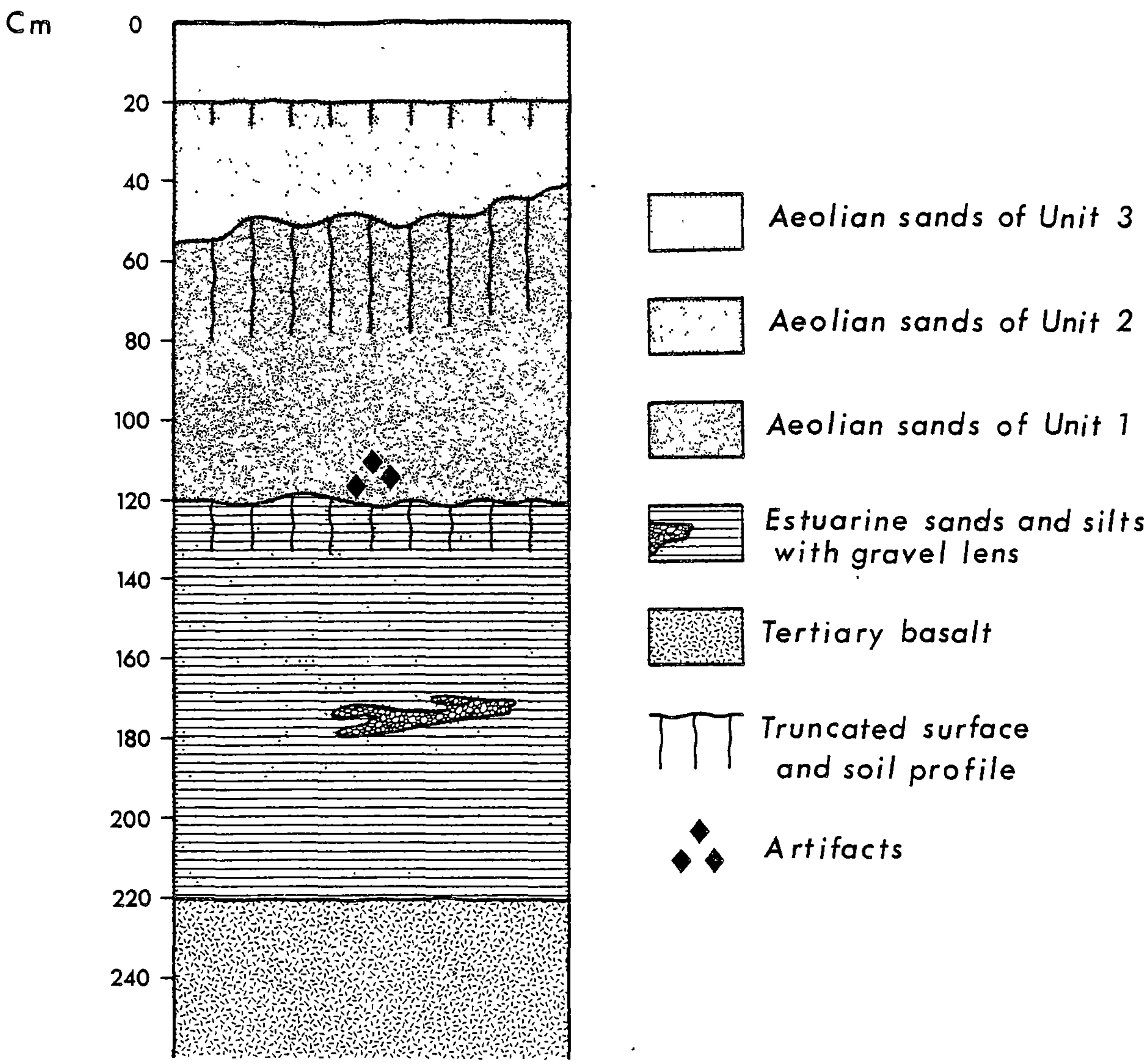


Figure 13. Type section at Old Beach showing Aboriginal implements near base of sandsheet

TABLE 5

TEXTURAL AND SOIL PROFILE DATA FOR THE OLD BEACH SANDSHEET[1]

(UNIT 1)

DEPTH CM	SOIL HORIZON	STRUCTURE AND REACTION	COLOR	TEXTURE	SAND %	SILT %	CLAY %	$^{E}Fe_2O_3$ %	$^{T}Fe_2O_3$ %	$^{T}Al_2O_3$ %	$^{T}Fe_2O_3 + {}^{T}Al_2O_3$ %	CLAY MINERALS M	I	I/M	K	Q
5-10	B	Moderately developed fine to medium, subangular blocky peds; slightly alkaline	2.5 YR 5/8	Sandy clay loam	58.26	16.87	24.85	1.25	2.46	8.81	11.27	x	x	xxx	xxxx	xx
10-15					59.18	17.52	23.31	1.06	2.68	10.18	12.86	-	-	-	-	-
20-25					64.85	15.69	19.46	1.06	2.91	11.02	13.93	x	x	x	xxx	xx
30-35	C	Single grained; neutral to slightly alkaline	5 YR 5/8	Sandy clay loam	68.09	10.84	22.52	0.35	2.18	8.34	10.52	-	-	-	-	-
50-55					59.40	11.52	29.07	0.97	2.52	9.09	11.61	xx	xx	x	xx	xx

1. M_z, σ_1 and S_k not derivable due to excessive silt and clay in the deposit.

The marked textural variations between Glenfield and Old Beach indicate that these sandsheets are derived from quite different alluvial source materials. The Glenfield deposit is most likely derived from well sorted alluvial sands containing little or no silt. In contrast, the high proportion of silt in the Old Beach sandsheet indicates a much more heterogeneous alluvial source. These variations between the sites reflect differences in drainage area, rock type, and the availability of specific source materials between the Derwent and Jordan catchments.

The form and position of the basal aeolian unit at Old Beach indicates a deflation source to the west in the emerged valley of the Derwent. The textural variations observed across the site most likely reflect a primary depositional pattern related to distance from the source area and variations in the alluvial material available for deflation.

The surface of Unit 1 is irregularly truncated and is unconformably overlain by an aeolian slopewash complex grouped as *Unit 2*. The thickness of the aeolian sediments vary considerably, but generally the deposit increases with distance inland where it is up to 1 m thick. The slopewash facies is less than 20 cm thick and only occurs locally in heavily eroded areas of the site.

At the type section Unit 2 is a massively bedded aeolian sand about 20 cm thick. Textural data for the unit are not available, but the deposit appears to be well sorted and consists predominantly of fine quartz sand with very little silt or clay.

In a heavily eroded area some 200 m southeast of the type section Unit 2 is represented by 10-20 cm of sandy slopewash (Site B). This material directly overlies the basal sandsheet, but in heavily eroded areas, it buries the high level alluvial sediments. The facies consists of a moderately consolidated sandy loam which is very thinly bedded into subhorizontal lenses. Each is distinguished by a thin segregation of finely divided organic matter and small twigs and charcoal fragments.

The form and position of the Unit 2 aeolian facies indicates that the deposit is derived from the mobilization of fine sandy sediments by westerly winds. The slopewash facies is clearly derived from local downslope reworking of the basal sandsheet in heavily disturbed areas of the site. The aeolian sediments could be derived from the deflation of alluvium in the Derwent channel. However, this possibility seems unlikely as the close modal similarity of the sands of Unit 1 with those of Unit 2 suggest a genetic relationship between the deposits. Unit 2 is more likely derived from the aeolian reworking of the surface of the basal sandsheet during a later period of disturbance at the site.

Unit 2 is unconformably overlain by a thin, irregular bed of aeolian sand which forms *Unit 3*. The deposit is up to 20 cm thick and only occurs overlying the sands of Unit 2. At the type section Unit 3 is about 30 cm thick and consists of well sorted, fine quartz sand. The unit is weakly consolidated and generally massive, but very thinly bedded, subhorizontal laminae occur locally. Very little silt or clay occurs, but finely disseminated organic matter and small charcoal fragments are present throughout the unit.

The sands of Unit 3 are most likely derived from the aeolian erosion of Unit 2 by westerly winds. This conclusion is further supported by the close textural similarity between the two deposits and the unconformity which truncates the surface of Unit 2.

Unit 3 is unconformably overlain by *Unit 4* which is between 0-50 cm thick and consists of very weakly consolidated aeolian sand. This deposit is not continuously distributed at the site, but appears to increase in thickness with distance inland. The unit is massively bedded and overlies the surfaces of all the older aeolian deposits.

At the type section, Unit 4 is 20 cm thick and also consists predominantly of well sorted, fine sand. This deposit contains ample evidence of European occupation and most likely formed during the latest period of disturbance at the site.

In conclusion, the basal sandsheet appears to be the only aeolian unit at the site that was derived from the deflation of Derwent Valley alluvium. The upper aeolian units are most likely formed by periodic disturbances of the site by the activities of Man.

<u>Pedogenesis</u> - Unit 1 is weathered and shows evidence of a moderately developed soil profile. The unconformity at the top of the profile indicates that the A horizon was eroded prior to burial by Unit 2.

The upper 15-20 cm of the profile, interpreted as the truncated B horizon, is generally reddish brown, and has a blocky structure with well developed cutans of clay minerals and iron oxides on the ped surfaces. The boundary between the B and C horizons is gradational, and the C horizon has single grained structure throughout. There is no evidence of mottling, free carbonate or other concretions in either horizon, although after drying, evaporation and capillary movement produce efflorescences of granular salt (NaCl) in both horizons.

The soil characteristics show considerable variation over the site.

Along the southern and southeastern portion of the deposit, the percentage of clay in the B horizon is some 10-20 percent less than at the type section. However, the degree of ped organization is similar over most of the site, and color differences between horizons are generally uniform. The apparently anomalous clay maxima in the C horizon at the type section is probably due to the perching of colloidal material at the contact of the relatively impermeable surface of the underlying alluvial sediments.

At the type section, the percentage of extractable iron oxide is highest in the upper 5-15 cm of the profile and closely corresponds with the clay maxima in the B horizon. The relationship between clay and extractable iron is further demonstrated as both these components increase near the base of the deposit. Total iron and aluminum oxide values are also highest in the lower part of the B horizon of the profile.

Kaolinite and the interstratified clay mineral are more abundant in the B horizon while montmorillinite and illite are present in higher proportions in the C horizon. The clay mineral and geochemical distribution in the profile suggest strong hydrolysis of primary mineral components under relatively acid leaching conditions. Montmorillonite most likely formed through the weathering of mafic mineral components with kaolinite as the end product under continuous leaching. The illite minerals may represent an intermediate stage of this process.

The extractable iron and sesquioxide values show significant differences between horizons in this particular profile. In contrast to the Glenfield Unit 1 profile, the Old Beach soil appears to be more strongly differentiated and better developed. Similarly, the more abundant kaolinite and interstratified clay mineral in the B horizon of this profile suggest a more advanced stage of weathering than at Glenfield which was characterized by an abundance of montmorillinite in both horizons. These differences could be due to the time involved in profile formation, but more likely reflect lithologic variations of source materials found between the respective drainage areas. A relatively weak profile is developed in the overlying aeolian sands of *Unit 2*. The upper 5-10 cm of this profile is only weakly oxidized and weathering of the deposit appears to have been minimal. The slopewash facies shows no evidence of a soil profile.

The Unit 2 profiles at Old Beach and Glenfield show similar degrees of weak pedologic organization. In addition, both deposits overly the unconformity which truncates the basal sandsheets at each site. This relationship and the similar degree of weathering in the sand units suggests that the deposits are soil-stratigraphic equivalents. There is no evidence of profile development in Unit 3. The deposit is uniformly dark and has a single grained structure throughout. Unit 4 shows no evidence of profile development and these sands have a single grained structure.

Since only traces of the various oxides could be expected from Unit 2, no chemical and clay mineral analyses were conducted for this deposit. The profile in the basal sandsheet is relatively well developed and probably formed over a prolonged period of stability. In contrast, the weakly differentiated profile in Unit 2 represents a much shorter period of soil development.

<u>Archeological and Radiocarbon Data</u> - The earliest evidence of Aboriginal occupation is several lithic fragments within the basal aeolian unit (Fig. 14). Of the six fragments, four have been positively identified

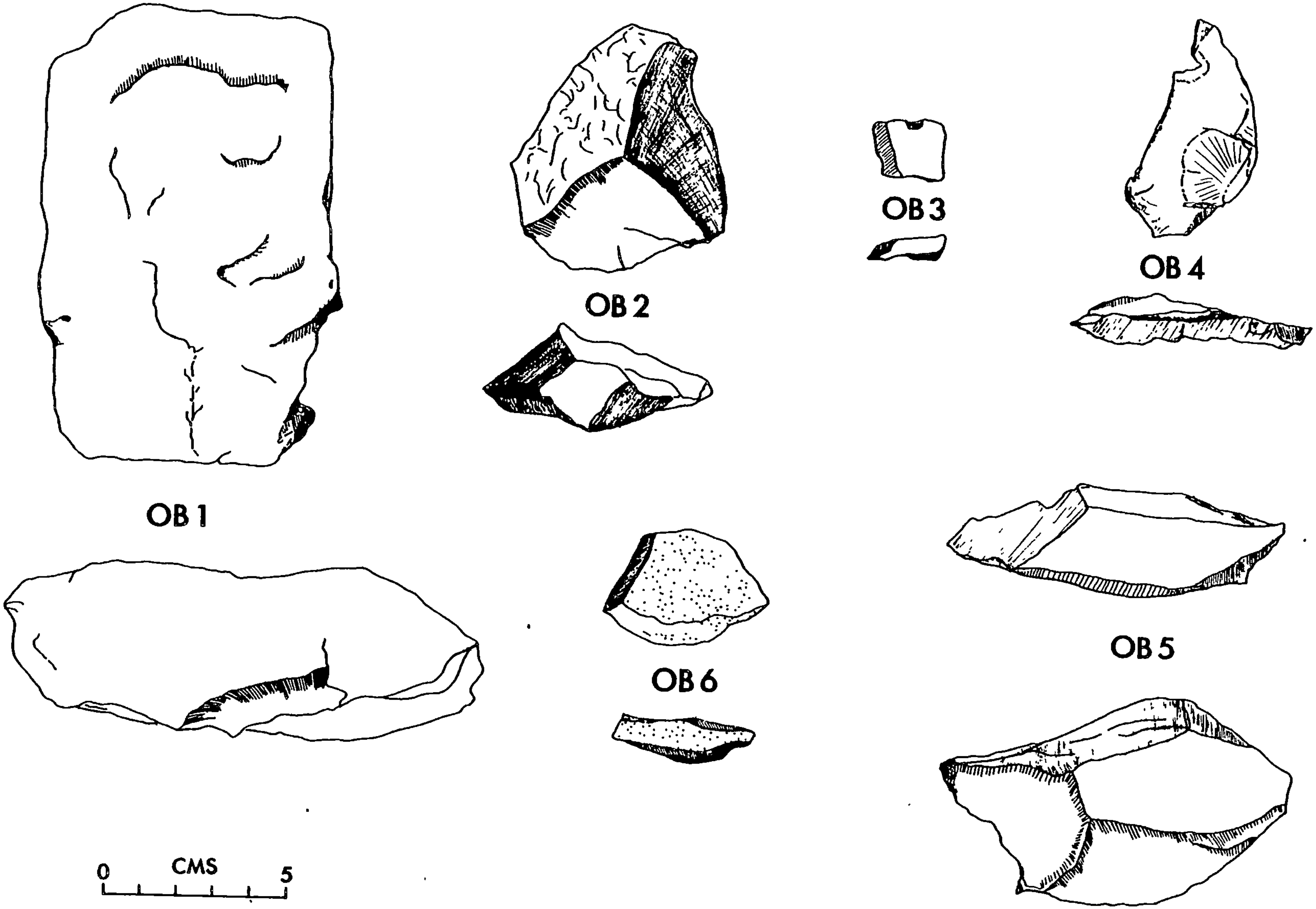


Figure 14. Aboriginal implements recovered from the basal sandsheet (Unit 1) at Old Beach

as worked implements on the basis of their morphological characteristics (Jones, pers. comm.). All of the identified material is composed of greyish-brown to bluish-grey, nearly pure quartzite of fine to medium texture. One of the questionable fragments, probably a small flake, is similar quartzite, while the other is a weathered basalt cobble. Their characteristics are as follows:

OB-1 Subangular to subrounded elongate Tertiary basalt pebble 13 x 7.5 x 3 cm; moderately weathered and coated with a thin film of red to dark red cutanic material. This fragment is unflaked; its human origin is questionable, but its presence within the aeolian sand unit is unnatural.

OB-2 A flake detached from a quartzite river pebble shows a bulb of percussion and two dorsal flake scars. Three further flake scars have been worked from a different platform. It is 6.7 cm long and exhibits arcuate chattermarks of probable fluvial origin on the unworked surface.

OB-3 A small quartzite flake probably of human origin, but no bulb of percussion shown. Maximum length is 2.3 cm.

OB-4 A flake detached from a quartzite river pebble showing percussion bulb on a ventral face with several negative flake scars on the dorsal face and arcuate chattermarks of probable fluvial origin on the unworked surface. Maximum length is 5.9 cm.

OB-5 A quartzite flake with well developed percussion bulb on the ventral face and a flat striking platform. There are at least six negative flake scars on the dorsal face. Maximum length is 9 cm.

OB-6 A quartzite flake with well marked bulb of percussion and three facets on the striking platform. There are two or three negative flake scars on the dorsal face. Maximum length is 4.5 cm.

The artifacts are simple flakes with sharp and unworn edges and show no evidence of secondary retouching. They cannot be classified in terms of specific typological characteristics or regional associations. The material shows no evidence of patination and the fragments are not covered with carbonate. However, they are coated with a thin film of red to yellowish-red, cutanic material.

OB-2 to 4 were found at the type section beneath the truncated weathering profile developed on Unit 1 (Site A), between 5-10 cm above the surface of the estuarine sediments (Plate 16). OB-1 was found in a similar stratigraphic position approximately 10 m to the north, on the other side of the easement trench. OB-5 and 6 were found near the base of Unit 1 approximately 200 m south of the type section in a small gully (Site B). The artifacts were *in situ* as there was no evidence of intrusive emplacement, and they clearly could not have been transported by aeolian saltation.

The possibility exists that some of the artifacts may have been introduced from above when the easement trench was dug above five years ago, but this seems most unlikely as the lithic material is coated with cutanic material. In the author's opinion, all the artifacts described

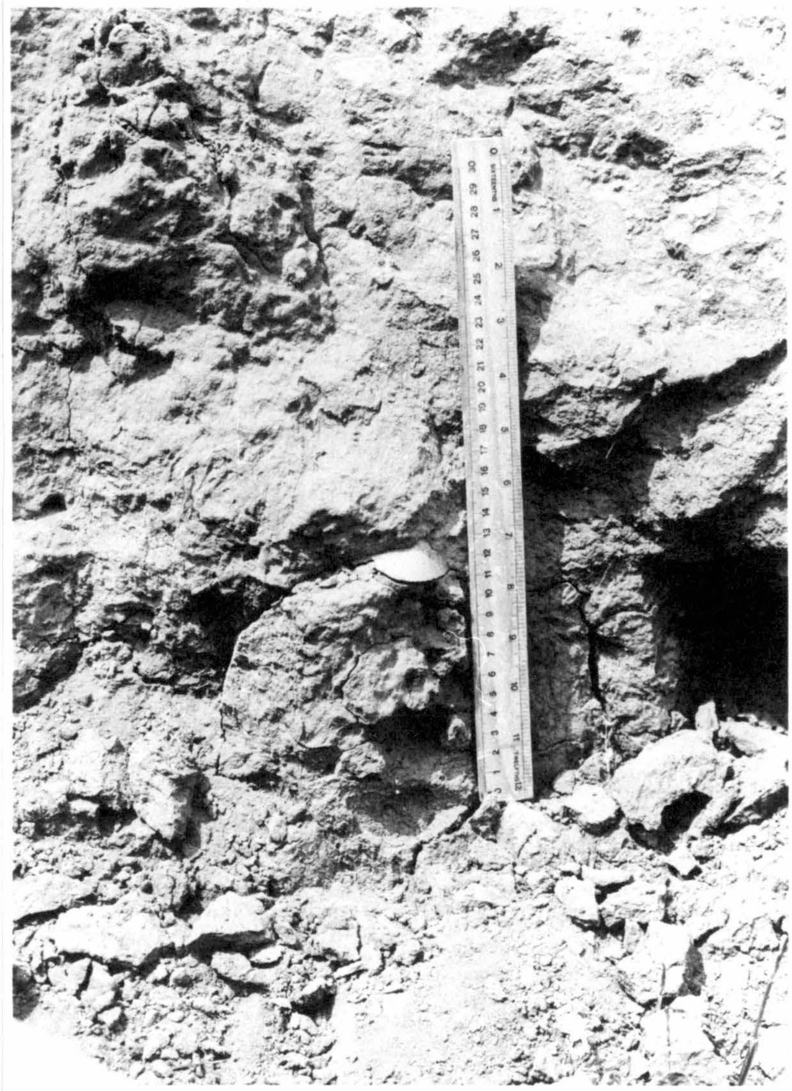


Plate 16. Aboriginal implement (OB-2) exposed near base of Unit 1 at Old Beach

are stratigraphically associated with the lower portion of the basal aeolian unit (Sigleo and Colhoun, 1975).

A reconnaissance excavation was dug approximately 3 m east of the type section, but unfortunately there was no evidence in this excavation of Aboriginal occupation below the surface of Unit 1. To date, no evidence of hearths or other datable material has been found in the unit.

In contrast, the overlying aeolian facies of Unit 2 contains numerous hearths, flaked implements and grinding stones. Lithic material is scattered everywhere at the site. Most of the artifacts are exposed on the surface of Unit 1. Some appear to have been lowered by the erosion of Unit 2 while others may have been dropped by the Aboriginals. A few small flaked implements and rounded basalt pebbles were recovered from Unit 2 in the excavation near the type section, and a thin shell midden is present on the surface of Unit 1 near the estuarine edge of the peninsula.

The exposed hearths consist of charcoal, organic staining and ash. Several of the hearths are associated with firestones. No bones were found, although some of the hearths contained the shells of a common edible mussel *Mylitus planulatus*. Several hearths occur in Unit 2 and are intrusive into Unit 1, but some may have been dug directly into the exposed surface of Unit 1, prior to the deposition of Unit 2.

Two of the hearths, located in a heavily eroded area near the southeastern portion of the site, were sectioned and the charcoal dated. OB-1 is elongate in section and the contact with the basal aeolian unit is sharp and well defined. The date on charcoal is 5,800 $\pm$ 130 BP (SUA-306), and the shell yielded a date of 5,600 $\pm$ 100 BP (SUA-307). OB-2 is a relatively shallow hearth and had a very diffuse contact with the basal

Plate 17. Aboriginal hearth intrusive into Unit 1 at Old Beach
(1,960 ± 105 BP)

unit (Plate 17). Charcoal from this hearth yielded a date of 1,960 $\pm$ 105 BP (SUA-308).

As far as can be determined, the dates give a range of Holocene occupation of this site. The surface occupation of Unit 1 and that associated with Unit 2 is later than and distinct from the phase indicated by the four artifacts described from Unit 1. Stratigraphically, the dates on OB-1 provide a minimum age for the truncation of the paleosol developed on the basal aeolian sandsheet and a maximum age for the deposition of Unit 2.

Evidence of Aboriginal occupation was not observed in either Units 3 or 4, suggesting abandonment of the site prior to deposition of these sands. Both of these units appear to be of recent origin and represent the effects of European land use in the area.

C. Bridgewater

Introduction - The Bridgewater sandsheet is located about 1 km west of the settlement of Bridgewater and borders the northern side of the Derwent estuary (Fig. 15). The site of aeolian deposition lies to the east of a relatively narrow segment of the river leading upstream to New Norfolk. The sandsheet is aligned WNW in relation to the estuary and is roughly triangular in shape with its base extending about 1 km along the Derwent. Directly west of the site is a large, semicircular embayment of the river now infilled with fine grained estuarine sediments to an unknown depth.

The sandsheet mantles a low, south-facing dolerite ridge in contact with the basalt to the east and Permian mudstones to the west. The sediments blanket the underlying rocks and the sandsheet preserves a low, undulating surface morphology. The original surface is disturbed and the deposit is sharply truncated at its seaward edge.

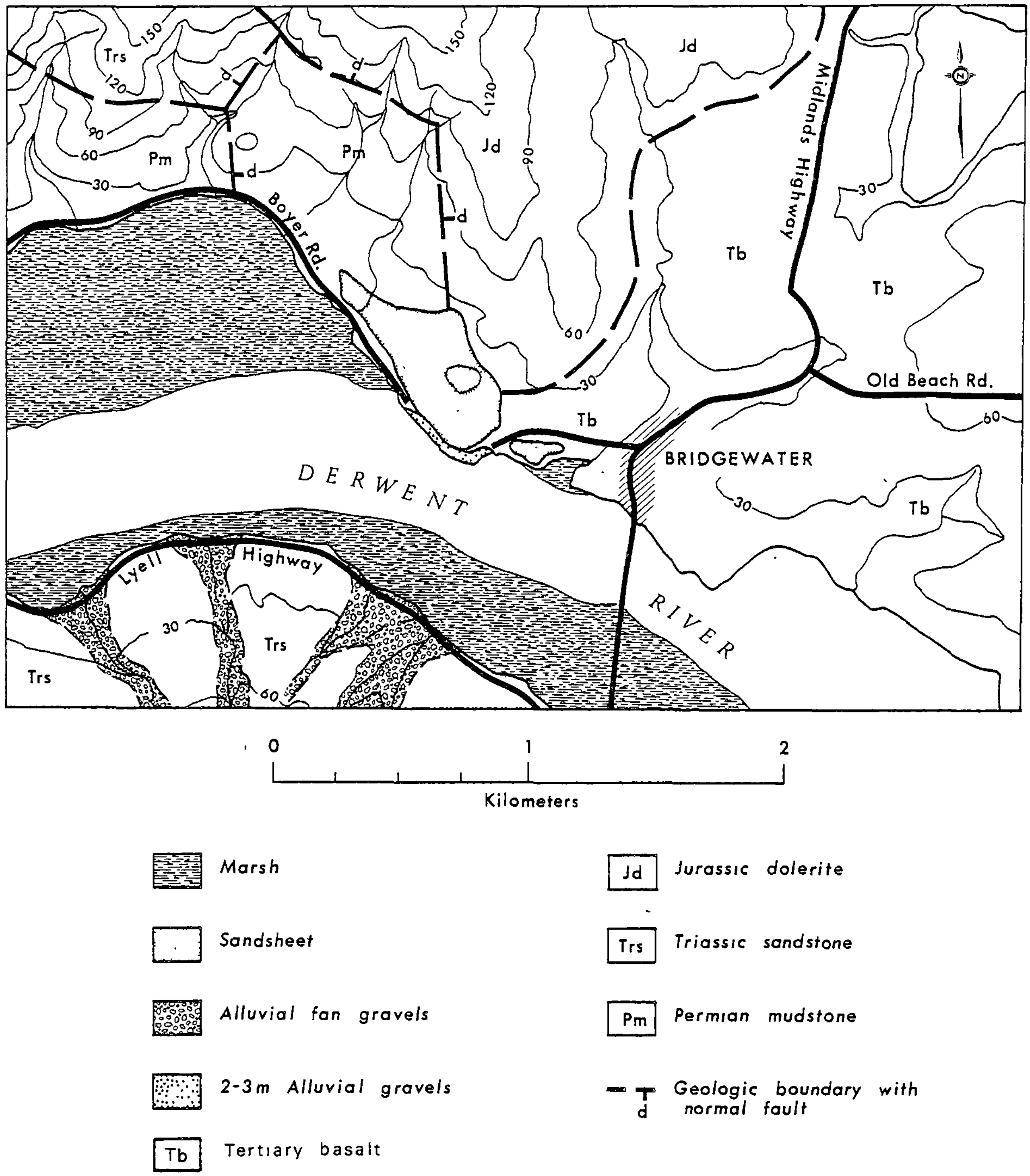


Figure 15. Location map of the Bridgewater sandsheet

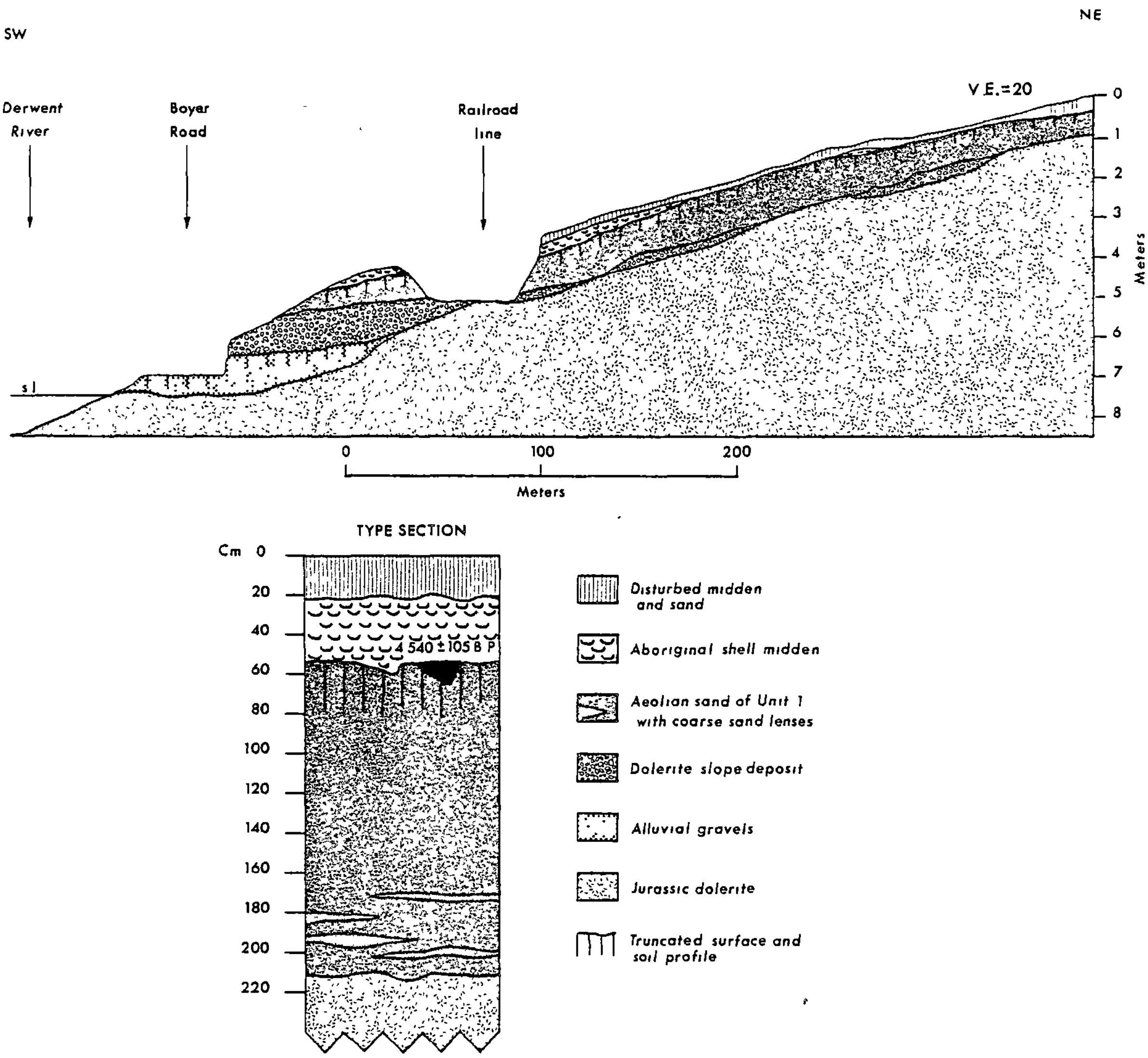


Figure 16. Cross-section of the Bridgewater sandsheet and stratigraphy at the type section

Plate 18. Type section of the Bridgewater sandsheet

Stratigraphy - The type section is located in a cutting along the Bridgewater-New Norfolk railway lines (Fig.16). The sandsheet is a single, massively bedded deposit between 1 - 2.5 m thick, and is overlain by an Aboriginal shell midden and a thin lens of disturbed sand (Plate 18). At the type section the sandsheets rests directly on weathered dolerite, but at most other locations it overlies dolerite colluvium.

The dolerite slope material is generally less than 1 m thick, and discontinuously mantles the rock surface and a portion of the high level alluvial gravels. The deposit is generally dark red and consists mainly of a medium to heavy clay with occasional fragments of weathered dolerite. The colluvium has a fine, sub-angular blocky structure with well developed stress cutans on the ped faces. Free carbonate occurs throughout as either small nodules or as locally developed interlocking sheets along the ped faces. The deposit shows no evidence of soil development as both regular downslope and differential movements appear to have prevented the establishment of a stable groundsurface.

The slope deposit locally shows a strongly contorted surface which is characterized by irregular diapiric structures (Plate 19). These intrude into the base of the sandsheet and are best exposed in a road-cutting some 200 m northeast of the type section. The structures are aligned parallel to the slope (3°SSW) and form a parallel series of down-slope alignments. The undulations are between 30-50 cm in height, 20-30 cm in width and the horizontal interval varies between 1 to 1.5 m. The surface of the sandsheet shows no evidence of the irregular morphology which characterizes the slope deposit and the sediments do not contain internal deformation structures.

Plate 19. Dolerite colluvium with diapiric structures at Bridgewater

Plate 20. Sharp contact between shell midden and aeolian sandsheet at Bridgewater

At the type section *Unit 1*, the basal sandsheet consists of a moderately consolidated sandy loam which is approximately 130 cm thick. The textural and soil profile characteristics for the sandsheet are given in Table 6. The sediments are poorly sorted and have a trimodal distribution of fine sand, silt and clay.

The sand fraction is well sorted and consists predominantly of quartz with some feldspars and dark mafic minerals. Silt and clay-sized material are most abundant in the upper 50 cm of the deposit,but decrease sharply with depth. Very thin bedded, subhorizontal lenses of very coarse sand and granules of quartz occur locally near the base of the deposit. Mean grain-size decreases with depth as the proportion of coarse sand in the deposit increases.

Texturally, the Bridgewater sediments are more like those of the basal sandsheet at Glenfield than those at Old Beach. The modal grain-size values are nearly identical between Bridgewater and Glenfield, and these two deposits contain similar amounts of clay in relation to depth.

The most significant textural difference between these two sandsheets is the relatively high proportion of silt in the Bridgewater deposit as compared with Glenfield. In this respect the Bridgewater sandsheet contains nearly the same amount and distribution of silt as does the Old Beach deposit. This type of relationship reflects the much finer source of the alluvial material available for deflation in the Derwent as compared with the Jordan catchment.

The Bridgewater sandsheet also shows some lateral variation in texture and is finer near the estuary. There are no sharp disconformities within the deposit and the sandsheet deposited by westerly winds as a massive wedge of aeolian material.

TABLE 6

TEXTURAL AND SOIL PROFILE DATA FOR THE BRIDGEWATER SANDSHEET[1]

(UNIT 1)

DEPTH CM	SOIL HORIZON	STRUCTURE AND REACTION	COLOR	TEXTURE	SAND %	SILT %	CLAY %	M_z	σ_I	$^E Fe_2O_3$ %	$^T Fe_2O_3$ %	$^T Al_2O_3$ %	$^T Fe_2O_3 + {}^T Al_2O_3$ %	CLAY MINERALS				
														MT	I	I/M	K	Q
10-15	B	weak to moderate, fine, subangular blocky; alkaline	2.5 YR 3/6	Sandy loam	71.20	15.45	13.31	3.96	2.14	1.23	3.56	9.97	13.53	xx	xx	x	xx	x
25-30					63.48	23.47	13.04	4.14	2.04	1.12	3.91	11.36	15.27					
50-55					74.33	12.14	13.52	3.78	2.17	0.62	3.82	9.86	13.68	xx	x	x	x	x
70-75	C	Single grained; alkaline	5 YR 4/8	Loamy sand	83.55	8.90	7.55	2.95	2.08	0.69	3.33	9.12	12.45					
100-105					85.37	5.37	9.25	2.92	2.09	0.43	3.63	8.86	12.49	xx	x	x	x	xx

1. S_k not derivable due to excessive silt and clay in the deposit.

Pedogenesis - The surface of the sandsheet is weathered and shows a moderately developed soil profile. The sharp unconformity as the top of the profile indicates that the A horizon was eroded prior to burial by, or during the formation of the shell midden.

The upper 30-40 cm of the profile is moderately oxidized and organized into blocky peds with weakly developed cutans of clay minerals and iron oxide. This portion of the profile, interpreted as the B horizon, grades to the single grained C horizon at depth.

Free carbonate is locally present in both horizons as weakly adhesive sheets along ped faces and cracks, and as small tubules and nodules. The sheets extend throughout the profile and are continuous with the carbonate in the overlying shell midden.

The gross profile characteristics vary considerably over the site. In localities where the deposit appears to contain more silt than sand, the structure of the B horizon ranges from single grained to very coarse prismatic peds with little or no cutanic development. In addition, free carbonate is only present where the profile directly underlies the shell midden. These variations indicate that lithology is important in controlling the structure of the B horizon and that the free carbonate is most likely intrusive from the midden and re-precipitated in the profile.

At the type section the extractable iron and sesquioxides values are highest in the B horizon and correspond directly with the clay maximum. Illite and kaolinite are the dominant clay minerals in the B horizon with montmorillonite increasing in abundance with depth.

The geochemical and clay mineral data indicate a chemically differentiated profile and a moderate degree of weathering. The abundance of kaolinite in the B horizon probably represents the end product of feldspar hydrolysis and continued leaching of montmorillonite in an acid environment. Iron was released and oxidized in the B horizon as a by-product. The illite and interstratified minerals either represent intermediate stages of weathering, or are weathered fragments of clay-sized muscovite and biotite.

Chemically, the Bridgewater profile is more similar to that developed at Old Beach than that at Glenfield. This relationship is especially marked in terms of the amount and distribution of extractable iron, and from the clay mineral assemblages which occur in both profiles. These similarities suggest that nearly the same intensity and/or duration of weathering occurred between the two sites with respect to the original parent materials.

Archeological and Radiocarbon Data - The sandsheet is irregularly truncated and is unconformably overlain by an Aboriginal shell midden between 20-40 cm thick. The contact between the two deposits varies from sharp and linear to gradational (Plate 20). The midden is locally intrusive into the underlying sands and the shell material forms irregular, undulating pockets.

The midden is most extensive along the margins of the estuary, but is primarily associated with the sandsheet. Small patches of shell locally overlie the low dolerite terrace near sealevel, but the midden was not observed in contact with the slope material or alluvial gravel.

The matrix of the midden is a black sandy loam which is weakly cemented by organic matter. The sand fraction appears to be well sorted and consists predominantly of fine quartz grains. The dark color of the matrix, due to a high proportion of organic matter, is uniform throughout the midden.

The midden contains very weakly stratified mussel *(Mytilus spp.)* shells with occasional fragments of rock oyster *(Ostrea spp.)* There are also unstratified fragments of charcoal with ash, numerous dolerite pebbles and a few cobbles, and infrequent flaked implements throughout. Charcoal obtained from near the contact of the midden with the basal sandsheet has been radiocarbon dated to 4,540 ± 105 BP (GaK-5593). This date indicates a minimum age for the deposition and weathering of the sandsheet, and gives an approximate maximum age for the midden.

There is no evidence of profile development in the midden, but shell carbonate has been leached from the deposit to the underlying aeolian sands. Some of the shells are differentially weathered, and their surfaces vary from relatively fresh to soft and powdery.

The predominantly sandy matrix of the midden is most likely derived from reworking of the surface of the underlying sandsheet. This conclusion is supported by the textural similarity of the midden sands with those which form the sandsheet, and from the evidence of the unconformity between the two deposits. This suggests that much of the A horizon of the profile formed on the sandsheet was disturbed by the activities of Aboriginals at the site and redistributed by westerly winds.

The upper surface of the midden deposit is locally truncated and is overlain by 10-20 cm of disturbed fine sand and shell fragments. The sand is uniformly reddish-brown and the grains are weakly bound by organic matter. The deposit also contains nail and wire fragments indicating that it was formed after European occupation of the area.

CHAPTER 5

AEOLIAN LANDFORMS FROM THE ADJACENT AREA

Aeolian landforms also occur in areas adjacent to the principal sites. Many are in the lower Derwent Valley, and isolated sandsheets and dunes occur throughout southeastern Tasmania. This chapter briefly describes several typical examples from the lower Derwent Valley and one from the Coal Valley in order to place the principal sites in a wider regional context.

Introduction - Aeolian sandsheets are widely distributed along the confined margins of the Derwent between Bridgewater and New Norfolk (Fig. 3); an east-west trending valley bordered on both sides by the steep slopes of the Mt. Faulkner-Mt. Dromedary horst. Here, the lower tributary valleys have provided depositional sites for fans of alluvial material derived from the upper slopes. The fans consist mainly of locally derived, poorly sorted and bedded, angular to subangular gravel in a matrix of sand, silt and clay. Many also contain similar, but unstratified and unsorted deposits which may be of mudflow origin.

Almost all of the fans are trenched by stream downcutting and the valleys are partially infilled with gravels reworked from the upper catchments. In some locations the inset fills are also trenched. These have been dissected prior to sealevel reaching its present position as the fills are graded to a slightly lower level than the present estuary (Wasson, pers. comm.).

Some of the low interfluves are locally mantled with thin sheets of unsorted, angular to subangular rock fragments and mineral debris. These deposits were derived by the erosion of regolith material which has been transported downslope. The deposits were most likely formed by solifluction processes in a former time of cold climate, although their exact origin has not been investigated in detail.

Aeolian sediments either overlie or are stratified within the alluvial fans, and some are found underlying slope deposits. The aeolian sediments have been informally divided into "lower" and "upper" sequences on the basis of their stratigraphic relations with the fans and relative degree of soil profile development.

Lower Aeolian Sequence - The earliest known evidence for aeolian activity is a small remnant of a sandsheet lying between two alluvial fan units at Red Gum, some 3 km east of New Norfolk (Fig. 17; Plate 21).

The lower 200 + cm at this sequence consists of poorly sorted and bedded fan gravels derived mainly from Permian mudstones. The gravels constitute about 60-70% of the fan and are in a light grey, very fine sand to silt matrix. The lower fan is either a waterlaid deposit or a poorly sorted debris flow, and is graded below present sealevel. Its surface is relatively unweathered and shows no evidence of profile development.

The lower fan member is unconformably overlain by an indurated, aeolian sandy loam which is up to 180 cm thick. This deposit consists predominantly of fine quartz sand with subordinate amounts of feldspars and mafic mineral grains. The sand is massively bedded and was deposited on the surface of the underlying gravels with little or no mixing of the sediments.

The sandsheet is weathered and shows relatively strong pedologic organization. The upper 30-35 cm is yellowish-red with well developed cutans on the interfaces. This portion of the profile, interpreted as the B horizon, locally has a parallelipedal structure and shows an increase in texture relative to the underlying sands. Calcified plant roots in vertical growth positions intrude the B horizon.

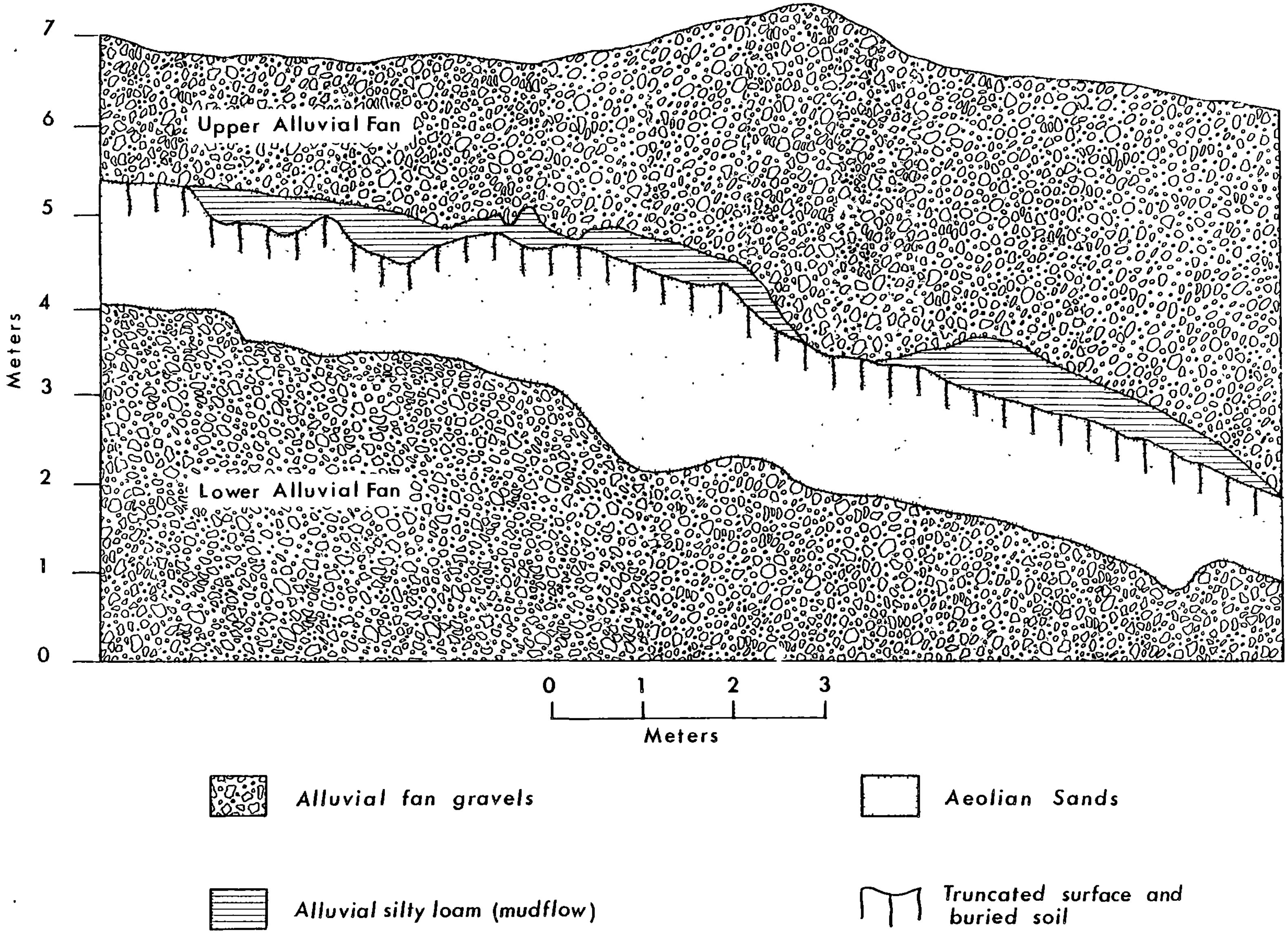


Figure 17. Stratigraphy of the aeolian sandsheet/alluvial fan sequence at Red Gum

Plate 21. Type section of aeolian sand/alluvial fan sequence at Red Gum

The lower boundary of the B horizon is gradational and the C horizon is lighter in color with a single grained to locally very coarse prismatic structure. This horizon contains small irregular mottles and there is no evidence of free carbonate.

The profile is truncated and the deposit is sharply overlain by a gravelly silt loam up to 30 cm thick. This deposit is massively bedded with fine parallelipedal structure and cutans on the ped surfaces. The unit also contains a few calcified root fragments and pebbles and granules of mudstone. This deposit is overlain by up to 300 cm of poorly sorted and bedded gravels similar to those in the underlying fan. The upper surface of this fan is weakly podzolized.

The Red Gum sequence indicates two major episodes of fan deposition separated by a period of aeolian activity and subsequent weathering. The gravels of the lower fan accumulated at a time of lower sealevel, and their deposition indicates local slope instability with a supply of angular debris from the catchment. The absence of a distinct soil profile on the lower fan surface suggests that only a short interval of weathering, if any, occurred between stabilization of the fan and the beginning of aeolian activity. The aeolian sediments are most likely derived from the west through the deflation of sandy alluvium exposed in the Derwent channel.

The high degree of pedological organization in the sandsheet with calcification of roots in the B horizon indicates that a prolonged period of stability and weathering occurred between episodes of fan deposition.

The period of soil formation in the sands ended with truncation of the deposit and burial by the thin silty loam. This lens may be a separate mudflow unit or it could represent the remobilized A horizon of the underlying profile soil. In either case the deposit has moved downslope and reflects the beginning of renewed slope instability with the deposition of the upper fan gravels.

The upper fan gravels are also graded below the level of the estuary and accumulated at a time of lower sealevel. As with the lower fan sequence, the upper gravels indicate at least local slope instability and a renewed supply of angular debris from the catchment.

Deposition of upper fan was followed by groundsurface stability and the formation of a weak podzolic soil. Facies of this profile are also developed across the upper surfaces of several slope and fan deposits in the area, and have formed during the most recent period of stability at each site.

The alluvial fan-aeolian sandsheet complex at Red Gum could correlate with a similar sequence at the Lime Kiln Point fan. Here a remnant of a sandsheet separating two alluvial fan members can be traced for about 300 m along a road-cut (Plate 22). The aeolian unit, 90-120 cm thick, is massively bedded, sandy loam which unconformably overlies more than 5 m of fan gravels (Plate 23).

The lower fan unit is graded below the level of the estuary and consists predominantly of coarse, angular fragments of locally derived mudstone and sandstone. The surface of the fan shows no evidence of profile differentiation, but some of the iron rich mudstone gravels are superficially oxidized. The sandsheet is weathered and the truncated B horizon is brown in color and organized into a blocky peds which are coated with cutanic material. The C horizon is lighter in color and texture, and has a mottled, single grained structure.

The truncated deposit is unconformably overlain by about 4 m of coarse, angular gravels similar in composition and texture to those of the

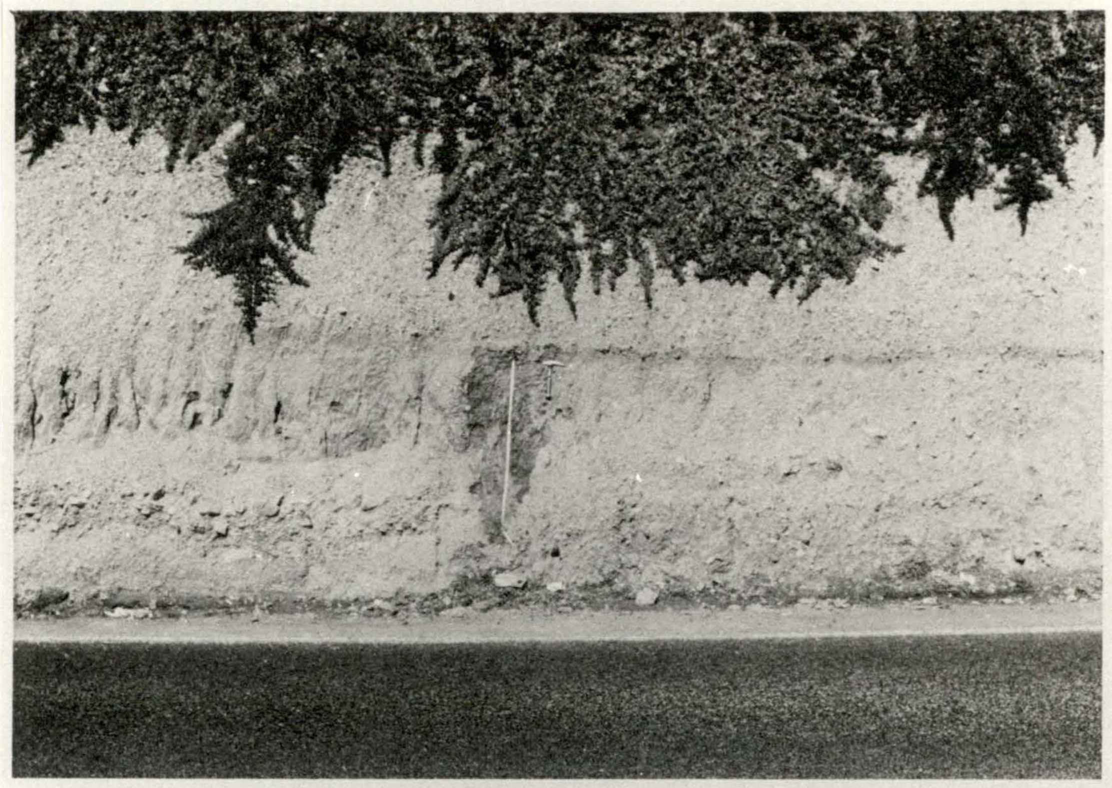


Plate 22. Aeolian sandsheet separating alluvial fan deposits at Lime Kiln Point

Plate 23. Detail of sandsheet and buried soil at Lime Kiln Point

lower fan. The upper fan is also graded below the level of the estuary and is truncated at the seaward edge. Portions of the upper fan surface are thinly mantled by a later aeolian deposit discussed in the next section.

The interstratified aeolian sand was most likely derived from the west by deflation of sandy alluvium exposed on the floor of the Derwent. As the aeolian sediments are not mixed with the lower gravels, this portion of the fan was probably stable throughout the phase of aeolian activity. The lower fan shows no evidence of profile differentiation other than the presence of weakly oxidized mudstones. Oxidation could have occurred during a very short period of stability prior to the beginning of aeolian activity. The truncated profile on the sandsheet does, however, provide clear evidence for stability and weathering prior to the deposition of the upper fan gravels.

The stratigraphic sequences at Red Gum and Lime Kiln Point are essentially similar and provide a basis of local correlation. The evidence indicates a double cycle of alluvial fan deposition separated by aeolian activity and weathering. Both fan series were deposited during a time of lower sealevel and the debris indicates conditions favoring slope instability in the catchments.

Each sandsheet was derived by the deflation of sandy alluvium exposed on the floor of the Derwent and both show evidence of strong pedogenic alteration. The profiles are similar in terms of gross pedologic structure, and weathering probably occurred during the same general period of stability. The duration and/or intensity of soil formation cannot be directly assessed, but, by comparison, the remains of these profiles are more strongly developed than are those which occur on the sandsheets at the principal sites.

<u>Upper Aeolian Sequence</u> - Aeolian sands and silts locally occur underlying thin, lobate sheets of poorly sorted slope material deposited near river level. One section (Site A) on the Lyell Highway, about 5 km east of New Norfolk, shows about 2 m of slope material overlying a thin remnant of an aeolian deposit (Fig. 18, Plate 24). The slope debris contains weathered dolerite cobbles and pebbles in a very fine sand to silt matrix.

The aeolian unit is a calcareous, reddish silty loam up to 70 cm thick. It is exposed for about 50 m, but was probably more extensive in the past. The deposit is heavily compressed by the overlying slope debris and shows a very coarse, columnar structure throughout. However, it is not strongly weathered and shows no evidence of marked profile differentiation or textural enrichment.

As far as can be determined this unit was deflated from the emerged Derwent floodplain by westerly winds. Deposition was followed by very weak weathering with oxidation of iron compounds, but drainage was not sufficient to remove free carbonates. The matrix of the overlying slope deposit is similar to that of the aeolian silt and indicates downslope reworking and truncation of the aeolian deposit.

This thin aeolian sheet may have been deposited during the initial phase of aeolian activity and could correlate with the sandsheets found within the Red Gum and Lime Kiln Point alluvial fans. However, it does not show the evidence of strong pedogenic alteration that characterizes the older aeolian sediments. On this basis, the unit is probably younger and deposited during a later phase of aeolian activity.

Locally, thin remnants of similar aeolian sheets overlie alluvial fans in other locations in the valley. These deposits occur discontinuously

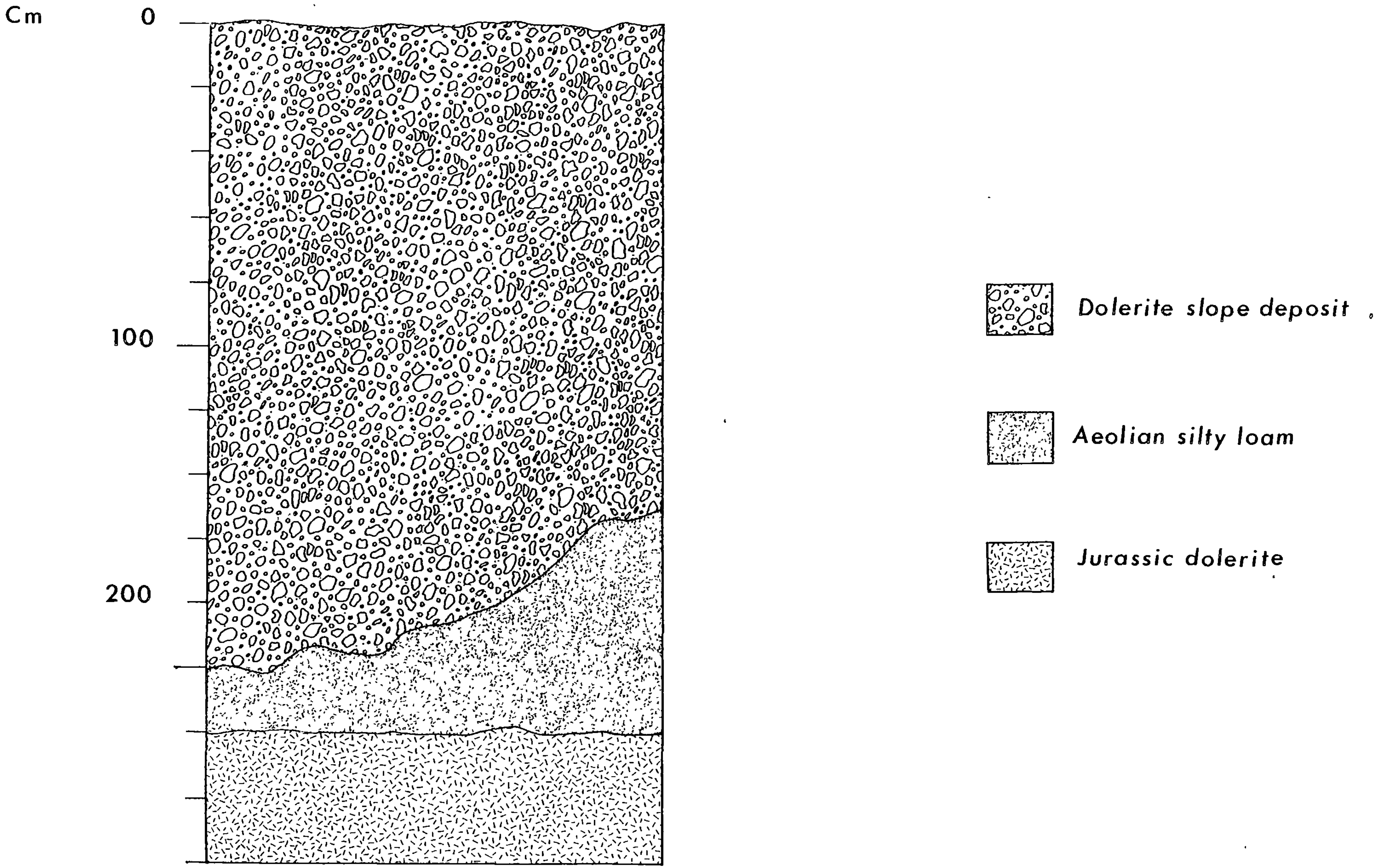


Figure 18. Stratigraphy at Site A along the Lyell Highway

Plate 24. Fine grained aeolian sediments buried by slope deposits at Site A along Lyell Highway

and range from a few centimeters to over two meters thick. Many of the deposits have been partially eroded during fan trenching and isolated remnants are exposed on the adjacent interfluves.

At Lime Kiln Point up to 60 cm of a brownish yellow, aeolian sandy loam directly overlies the surface of the upper alluvial fan gravels (Fig. 19). The sandsheet consists predominantly of fine quartz sand and silt, and mantles the surface of the fan. The sands do not appear to be strongly weathered, as there is only weak ped development and textural differentiation in the B horizon. Its position on the fan suggest that the sediments were derived by the westerly deflation of sandy alluvial material once exposed on the floor of the Derwent.

The sandsheet is truncated and overlain by a thin veneer of brown, gravelly sandy clay up to 30 cm thick. This unit contains about 30 percent clay and between 10-15 percent pebbles and granules locally derived from the Permian sediments. The gravels can be traced to a position directly overlying the fan and across the contact where the aeolian deposit wedges out. This indicates that the gravelly unit is a slope deposit, incorporating both the aeolian sediments and locally derived slope debris. The slope deposit is continuous from the surface of the fan to the adjacent hillslope where it can be traced upslope to a position where a truncated terra rossa occurs locally on the Berriedale limestone. The terra rossa is apparently a paleosol and its formation predates the slope material.

The lateral extent of the colluvium indicates that it is partially derived from the downslope mobilization of residual soil material. On this basis, the slope material resembles a *limon rouge* similar to those described

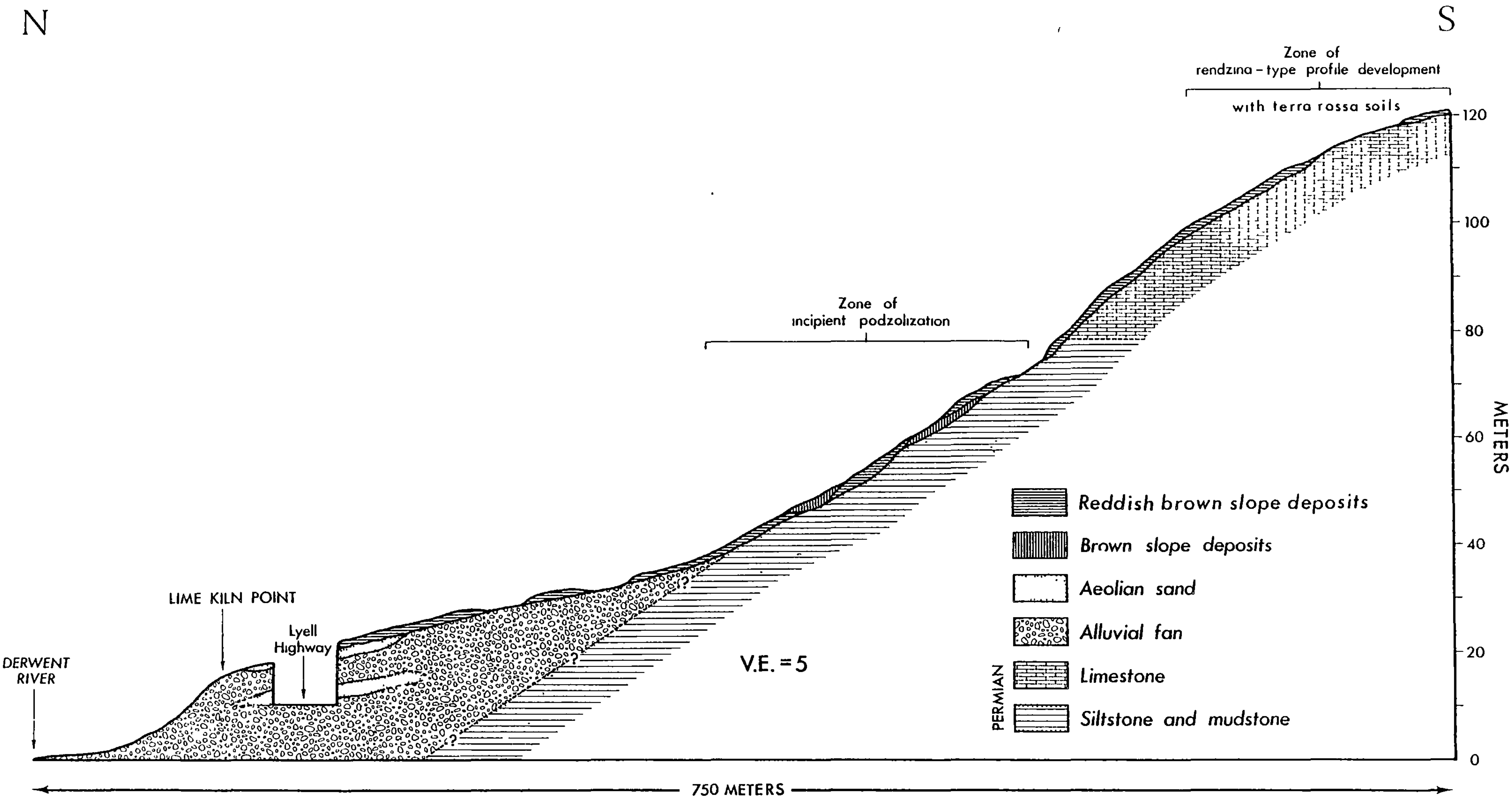


Figure 19. Cross-section of the alluvial fan sequence at Lime Kiln Point

by Butzer (1968) from Spain. The colluvial deposits on this ridge are further complicated by the presence of additional slope debris derived from apparently younger rendzina soils on the limestone. Since the hillslope shows evidence of human and animal disturbance, these slope deposits probably formed after European occupation of the valley

Other aeolian deposits occur on some alluvial fan surfaces. The best example is at Site B along the Lyell Highway, about 1 km west of Lime Kiln Point (Plate 25). In the lower portion of the valley a small alluvial fan occurs which is graded below sealevel. Most of the fan has been removed, but thin remnants are preserved against the valley sides and on the adjacent interfluves. The main section is exposed on the western side of the valley and shows two superimposed aeolian sheets overlying a thin radial portion of the fan.

The lower unit is a massively bedded, silt loam up to 225 cm thick. These sediments accumulated on the upper surface of the fan and are mixed with the alluvial gravels. The aeolian sheet is weathered and shows evidence of pedologic organization (Plate 26). The B horizon is reddish brown and organized into blocky to columnar peds which are coated with very weakly developed cutans.

The C horizon is lighter in color and has a single grained structure. This horizon contains thin, vertical sheets of weakly adhesive free carbonate and occasional nodules. The A horizon of the profile is missing and was apparently stripped prior to the deposition of the overlying aeolian unit. The upper aeolian sheet is also a massively bedded, silty loam, locally up to 125 cm thick. The contact between the units is sharp and linear to locally undulating. The deposit contains some pebbles and granules, but was not observed in direct contact with the fan.

Plate 25. Fine grained aeolian sediments at Site B along Lyell Highway

Plate 26. Detail of Site B showing buried soil developed on lower aeolian deposit

The upper unit is exposed at the groundsurface and shows evidence of pedologic organization. The profile consists of an organic A horizon up to 40 cm in thickness which contains occasional root and animal casts (krotovinas). This portion of the profile grades to a thin, weakly oxidized B horizon which shows no evidence of cutanic development and only a slight increase in texture relative to the underlying C. The lower boundary of the B is gradational and the C horizon contains soft, weakly adhesive sheets and infrequent nodules of free carbonate. The entire profile is organized into a well developed, very coarse prismatic structure.

Both sheets mantle the interfluve and decrease in thickness westward towards a large semicircular embayment of the Derwent. The sediments are texturally and structurally similar to loess and both units were derived by the westerly deflation of fine grained alluvial material exposed in the Derwent valley. The mixing of fan gravels in the lower aeolian sheet suggests that the fan was only active during the first phase of aeolian deposition.

This sequence indicates that the period of slope instability and fan deposition was synchronous with the phase of aeolian activity. However, there is no evidence of renewed fan deposition at this location during the accumulation of the upper aeolian unit.

The lower sheet at Site B may correlate with the earlier phase of deflation recorded from Red Gum and Lime Kiln Point. However, the deposit does not show the relatively strong pedogenic alternation found in the older deposits, even with respect to differences in parent material. By comparison, the truncated B horizon in the lower sheet is more similar to those found on the sandsheets at Bridgewater and Glenfield. This observation does not preclude the possibility that much of the profile could have been removed by subsequent erosion. However, a complete profile on the lower sheet was not observed, and without further evidence, there is no basis to correlate this deposit with the older interstratified sandsheets.

The profile on the upper aeolian sheet is not truncated and is characterized by the accumulation of organic matter in the A horizon with a weakly developed illuvial horizon. This profile resembles a minimum prairie soil (brunizem) and probably correlates with the podzolic soils formed on the upper fan and slope deposits in the area (Kubiena, 1953).

Aeolian deposits in southeastern Tasmania outside the lower Derwent Valley include isolated sandsheets, dunes and lunettes, depending on the local geomorphic environment. Most of these have not been investigated, but a dune at Malcolms Hut has provided some time control for the later period of widespread aeolian deposition in southeastern Tasmania and the lower Dewent Valley. Only the most important characteristics are included here and more detailed research on this site is being conducted by Dr. E. A. Colhoun.

Malcolms Hut is about 30 km east of the lower Derwent Valley and 4 km southeast of Richmond (Fig. 3, Plate 27). This dune occurs west of the Coal River Valley and overlies part of a complex surface of low-angle, coalescing alluvial fans. These fans are largely undissected,but consist mainly of mudstone, sandstone and dolerite gravels locally derived from the Permo-Triassic and Jurassic rocks of the Meeham Range to the west.

In some exposures, the fan gravels are heavily indurated and strongly weathered, while at others they are unconsolidated and relatively fresh. The different degrees of weathering are problematic and several generations of fans may be present in the valley. The dune at Malcolms Hut unconformably overlies the truncated surface of a strongly weathered alluvial fan and a significant hiatus probably exists between the end of fan deposition and the period of aeolian activity.

Plate 27. Aeolian sandsheet at Malcolms Hut (15,740 ± 700 BP)

Plate 28. Detail of Malcolms Hut sandsheet showing bedding and truncated B horizon of podzol

The dune covers a small area and most of it has been disturbed and removed by quarrying. The sediments consist of well sorted, fine sand up to 3 m thick (Plate 28). The sands are weakly consolidated and consist predominantly of quartz. The dune locally contains thinly bedded lenses of poorly sorted, very coarse grains and granules near the base. The sand has been deposited for the most part as very thin, planar cross-beds. Charcoal on the bedding planes has been radiocarbon dated to 15,740 ± 700 BP (SUA-376). The charcoal sample was collected from a small area in the dune between 1-2 m above the fan surface and the date provides an approximate age for the phase of aeolian activity (Colhoun, pers. comm.).

The exact source of the dune sediments is not known, but the orientation of the cross-beds suggests that the sands have been deflated by westerly winds from an adjacent alluvial fan surface. The basal, very coarse grains and granules suggest reworking of channel material at the site by high intensity, westerly winds. The period of deflation probably occurred contemporaneously with aggradation on the adjacent fan.

Aeolian activity was followed by groundsurface stability and podzolization of the sands. The A and part of the B_h horizon of the profile have been removed by quarrying and other surface disturbances. Podzolization of the deposit probably occurred throughout the Holocene until truncation occurred following European occupation of the area.

The above review of selected sandsheets and dunes in the lower Derwent Valley and elsewhere in southeastern Tasmania reveals a complex sequence of aeolian activity associated with at least two major periods of slope instability and alluvial fan deposition. Periods of aeolian activity and fan deposition occurred at a time of lower sealevel in the Derwent estuary, and the evidence implies cycles of widespread surface instability.

The age of the first phase of deflation cannot be directly determined; however the date from Malcolms Hut dune indicates that the last major period of aeolian activity occurred during the later part of the Last Glacial Stage.

CHAPTER 6

INTERPRETATION AND CORRELATION OF THE PRINCIPAL SITES IN THE LOWER DERWENT VALLEY

There is evidence for several episodes of aeolian activity and at least two major cycles of fluvial and/or estuarine aggradation in the lower Derwent Valley. The orientation of the sandsheets in relation to the drowned valley of the Derwent indicates that periods of deflation occurred at times of lower sealevel. The locations at which the Holocene coversands occur are also sites of Aboriginal occupation and require an interpretation involving redistribution of previously deposited materials. Table 7 presents a tenative correlation of the major events recorded from the principal sites.

Alluvial Sequence - The high level sediments at Old Beach, Bridgewater and in the lower Jordan Valley are remnants of an alluvial and estuarine fill deposited on a portion of an extensive strath terrace. The rock surface is up 15 m above HWST and was probably formed during one or more periods of prolonged fluvial erosion and lateral planation. As the surface is cut across basalts of Tertiary age, its formation could have taken place at more than one time until the late Pleistocene.

Deposition of the high alluvial sediments occurred at a time of widespread aggradation and infilling of the Derwent and Jordan Valleys. As the high level sediments at Old Beach and in the lower Jordan Valley occur at similar elevations above present sealevel, and are not radically different in lithology, they are considered facies deposited during the same general period of aggradation.

The lower Jordan alluvium was deposited under conditions of base-level stability when the river infilled the valley with sediments approximately

TABLE 7

PROVISIONAL LATE QUATERNARY SEQUENCE FROM THE PRINCIPAL SITES IN THE LOWER DERWENT VALLEY

GEOLOGIC AGE	LOWER JORDAN VALLEY	GLENFIELD	OLD BEACH	BRIDGEWATER
HOLOCENE	Alluvial silts, clays and gravels Channel Incision	Coversands Unit 4 Unit 3 (210 BP) (1,245 BP) Unit 2 (2,055 BP)	Coversands Unit 4 Unit 3 (1,960 BP) Unit 2 (5,800 BP)	Surface sands Shell midden (4,540 BP)
LAST GLACIAL STAGE	Low Terrace alluvial sands and silts Scree deposits Channel incision	Aeolian sandsheet (Unit 1) Slope deposits	Aeolian sandsheet (Unit 1) Delta incision	Aeolian sandsheet (Unit 1) Slope deposits Channel incision
LAST INTERGLACIAL STAGE	High Terrace alluvial sands, silts and gravels	Aeolian sand lenses (?)	High Delta sands, silts and gravels	Alluvial sands and gravels

Soil

9-15 m above present sealevel. The sediments appear to have been continuously deposited in the lower reaches of the valley and were thickest at the seaward edge of the strath terrace. At Old Beach alluvial and/or estuarine sedimentation extended some distance inland from the present margins of the estuary.

Alluvial deposition occurs when the availability of sediment greatly exceeds the amount which can be removed by fluvial and/or estuarine erosion. Aggradation in the lower reaches of a river can result from a variety of interrelated, environmental factors, but for the purposes of this discussion the causes may be grouped as tectonic, climatic and/or eustatic (Leopold et. al., 1964).

The last known period of tectonic activity in southeastern Tasmania is thought to have occurred in the early Tertiary (Hills and Carey, 1949). Since there is no evidence of post-basalt faulting in the lower Derwent Valley, tectonic activity is unlikely to have initiated aggradation by supplying abundant sediment from a rising land mass. In a tectonically stable estuarine environment such as the lower Derwent Valley, fluvial processes are more likely to be controlled by sealevel oscillations and their direct effect on baselevel stability. The high level alluvial and estuarine sediments are most likely related to climatic or eustatic factors acting either independently or in conjunction. Climatic-induced erosion could have contributed sediments at any time, but aggradation in the lower reaches of these valleys seems to have been more closely related to the presence of relatively high sealevels in the estuary during the late Quaternary period.

Also, because the gradient of the high terrace in the lower Jordan is less than that of the modern floodplain, the period of high level aggradation appears to be primarily related to a rise in baselevel in the estuary.

During the change in baselevel aggradation would have extended upstream until a new, stable profile was established with respect to baselevel attained, and to the availability and caliber of sediment from the catchment.

The upper limit of transgression cannot be determined in the lower Jordan Valley, but sedimentation occurred to a minimum height of 12 m above present sealevel. A hydrologic change causing aggradation in the lower reaches of this valley would also cause sediment infilling of the Derwent. The sands, silts and gravels overlying the strath terrace at Old Beach are considered to be a remnant of a former estuarine fill and are most likely part of a high delta deposited at the Jordan confluence similar to the present delta, but graded to a higher sealevel.

This interpretation is tentative, and based on the limited exposure of the high terrace deposits, their relationship to the modern channel gradient, and observations on the pattern of alluvial and estuarine deposition in the local area. If the reconstruction is valid, then the relative elevation of the high terrace deposits could indicate a baselevel transgression of similar magnitude to that of the Last Interglacial Stage (Fairbridge, 1961; Flint, 1971; Zeuner, 1959).

This explanation is further supported by previous work on eustatic terrace and marine levels in Tasmania; however, there has been little coordinated research in this field. Lewis (1935) identified three main terrace suites in the lower Derwent (35-50 m, 7-18 m, and 2-5 m), and related these with European interglacial sequences. Lewis correlated the 9-12 m level at Old Beach and in the lower Jordan Valley with the "Malanna-Yolande" interglacial stage (Holstein-Yarmouth).

Davies (1959b) also identified an extensive 3.5-4.5 m level in southeastern Tasmania and correlated it with either the Last Interglacial or a Last Glacial interstadial high sealevel. Other terraced marine deposits up to 22 m above present sealevel have been identified at South Arm (Colhoun, pers. comm.) and terraced fluvial/estuarine sediments have been found at similar levels in the lower Coal River valley (Goede, pers. comm.).

Although the history of these deposits and terrace levels has not been examined in great detail, the evidence from South Arm suggests that this area experienced a marine transgression to slightly over 20 m, probably during the Last Interglacial Stage (Colhoun, pers. comm.). If this proves to be correct, the high alluvial deposits at Old Beach and in the lower Jordan Valley are most reasonably explained as having been formed during the Last Interglacial glacio-eustatic rise in sealevel.

High level, alluvial deposition was followed by weathering as indicated by the well developed soil profiles. The profiles are strongly differentiated and their gross pedologic characteristics suggest a weathering episode of relatively long duration. The Jordan profile does not contain free carbonate and most likely formed under freely drained conditions. In contrast, the thin, vertical sheets of carbonate in the Old Beach profile indicate either incomplete leaching under impeded drainage conditions or possibly a higher content of carbonate in the deposit as compared with the Jordan sediments.

Sufficient moisture must have been available for the illuviation of clay, and hydrolysis and oxidation of iron compounds suggest that temperatures may have been as warm or warmer than present. This evidence suggests that the main episode of weathering may have occurred in a relatively warm, subhumid environment, probably during the later part of the Last Interglacial and early in the Last Glacial Stage (Birkeland, 1965).

Many of the isolated alluvial remnants along the Derwent may also have been deposited under sealevel control during the Last Interglacial Stage and weathered until truncation. This interpretation is supported by their similar elevation above present sealevel and the advanced weathering observed in the sediments. On this basis, the deposition of the alluvial gravels at Bridgewater could have occurred sometime during or preceding the Last Interglacial Stage as the clasts show comparable weathering to those in the high alluvial deposit in the lower Jordan valley. This marked alteration of dolerite clasts has not been observed in deposits known to be of Last Glacial or younger age.

Sediment infilling in the lower Derwent and Jordan Valleys was followed by channel incision and terrace formation. As the terraces in the lower Jordan are at nearly the same elevation above the present valley floor, initial downcutting and erosion could have occurred gradually. However, the lack of terrace continuity along the valley sides suggests the subsequent development of a laterally meandering and progressively downcutting channel under conditions of a rapidly falling baselevel (Leopold et. al., 1964). Most of the fill at the Jordan confluence was also removed with only thin remnants being preserved on the low interfluves.

The period of general baselevel lowering and channel erosion is tentatively correlated with the glacio-eustatic lowering of sealevel which occurred during the early part of the Last Glacial Stage (Flint, 1971). In the lower reaches of the drowned Jordan segment the potential local baselevel is the rock floor of the valley, approximately 30 m below present sealevel at the confluence. Erosion in the lower reaches of the Derwent and its major tributaries would most likely have continued until the sea began to flood the valley again during a subsequent glacio-eustatic rise in sealevel.

<u>Basal Sandsheets</u> - The exact ages of the basal sandsheets (Unit 1) at Old Beach, Bridgewater and Glenfield are difficult to assess as radiocarbon control is not available. The dated hearths pertain to subsequent Aboriginal occupation of the sites during the Holocene and only provide minimum ages for the truncation of the soil profiles formed on each deposit. Thus, the maximum age for the Old Beach sandsheet post-dates the deposition and weathering of the high terrace alluvial sediments, while that for Bridgewater and Glenfield follows the accumulation of the slope deposits which underlie these sandsheets.

Since profile truncation took place during the Holocene, the basal sandsheets were most likely deposited during the later part of the Last Glacial Stage. In the absence of direct radiocarbon control, the basal sandsheets can only be considered equivalents on the basis of their sedimentary characteristics, geomorphic and stratigraphic relations, and relative degree of soil profile development.

a. <u>Sedimentary Characteristics</u> - The samples from the sandsheets all revealed a bimodal distribution of fine sand and clay; this characteristic was most pronounced in the Old Beach samples. Silt was present in varying proportions in the Bridgewater and Old Beach samples, but was negligible in the Glenfield sediments. Due to the inclusion of the fine material within the sandsheets, the sediments appear to be poorly sorted, fine skewed and are atypical of most modern aeolian deposits.

However, in nearly all cases, the sand mode occupied the 2.5 to 3.0 Ø range, and coarser sands exhibiting a - 1.0 to + 1.0 Ø range were locally found near the base of the Bridgewater sandsheet. The predominance of the fine sand in all three sandsheets is significant as it reflects both the original sorting of the sediments and the transporting energy involved during deflation. The coincidence of sands within the relatively narrow modal range suggests comparable wind velocities during the deposition of all three sandsheets. This relationship, while not conclusive evidence of correlation, does provide an important basis of comparison between the deposits.

Although the textural parameters of mean grain size, sorting and skewness could not be determined for many of the sediment samples, the amount and distribution of silt and clay in the sandsheets suggest that they are poorly sorted and fine skewed. In this regard, the sandsheets appear to be relatively similar as each contains a significant proportion of silt and/or clay in the upper portion of the deposit. Between sites, the Bridgewater and Old Beach samples appear to be most similar due to their higher percentages of fines, especially the silt fraction. In contrast, the samples from the basal sandsheet at Glenfield are somewhat better sorted than those from the other sites due to a much lower proportion of clay and negligible silt content. Given the gross variations in texture between the sites, similarities between Old Beach and Bridgewater appear to be a function of the silt content. This criterion alone tends to isolate the Glenfield sediments from those of the other sandsheets.

The textural variations between the sandsheets result primarily from the amount of fine material in the deposits and its overall effect on sorting and skewness characteristics. There are two possible sources for the silt and/or clay fraction in these sandsheets: (1) an infiltration of windborn fines during aeolian deposition; and (2) weathering of primary minerals during subsequent pedogenesis of the deposits. Without detailed micromorphological analysis of the silt-clay fraction of these deposits, it is not possible to accurately determine what proportion of the fine material in each sandsheet is of sedimentary origin or formed through pedogenic processes. The presence of a fine aeolian component at Bridgewater and Old Beach cannot be completely discounted due to the lateral variations in texture and high silt content observed at these sites.

The grain size data have been obtained from a single section at each sandsheet and the original textural characteristics have been strongly modified by weathering processes. Thus, comparative evaluation of the grain size distributions between the sites can only be of a general nature. In this respect, the gross sedimentary characteristics presented here do not provide conclusive evidence in support of the correlation of the units. Certain trends are apparent, and the relative similarity of the sand mode and the inferred sorting and skewness relationships provide some basis of comparison between the sandsheets.

b. Geomorphic and Stratigraphic Relations - The orientation of the sandsheets points to the persistence over time of prevailing westerly winds. This relationship indicates that there has been little or no change between the paleowind direction and that which prevails today. Thus, the sandsheets must have accumulated under similar wind circulation patterns which seem to have persisted throughout much of later Quaternary time. Since extensive aeolian erosion at the present time is directly influenced by human and animal disturbance at favorable sites, the basal sandsheets were most likely deposited under different conditions of temperature, precipitation and vegetation cover.

The lee positions of the Bridgewater and Old Beach sandsheets indicate alluvial deflation sources once exposed in the Derwent Valley. Since the present tidal range on the estuary is not of sufficient magnitude to expose extensive areas available for deflation, the sandsheets must have accumulated at a time of lower sealevel. These general geomorphic relationships provide evidence in support of a Last Glacial age for the sandsheets.

At Bridgewater the aeolian sands mantle weathered dolerite and its locally derived slope material. The colluvium pre-dates the formation of the sandsheet and probably formed sometime during the Last Glacial Stage. The irregular surface morphology of this deposit is a gilgai phenomenon and results from differential movement of expandable lattice clays in the deposit (Hallsworth et. al., 1955). The surface contortions and diapiric structures are aligned normal to the hillslope and could be either lattice or linear gilgai features (Stace et. al., 1968). Gilgai have no particular climatic significance, although formation requires the intermittent wetting and drying of the subsoil. Development may be a continuous process through time and these features may even post-date aeolian deposition.

The Bridgewater sandsheet is most likely derived by the deflation of sandy alluvial sediments exposed in the large, semicircular embayment directly west of the site as this area was quite possibly an extensive surface of floodplain deposition in the emerged Derwent Valley. The coarse basal lenses indicate surface creep of material located very close to the site. The coarse sands could have been deflated from the floodplain source, but are more likely derived by reworking of the alluvial sands underlying the dune. These lenses indicate high intensity, westerly winds during deflation and intermittent deposition, at least during the initial stages of aeolian activity. The locally high silt content in this sandsheet indicates that large amounts of fines were being transported in suspension during the main period of aeolian activity.

The Old Beach sandsheet overlies high level estuarine and/or alluvial sediments described earlier. The position of the sandsheet indicates a deflation source near the confluence of the Jordan River with the Derwent. As the gradient of the Jordan thalweg is steeper than that of the Derwent at this particular location, a small, low angle fan of alluvial material could have accumulated at the confluence during the Last Glacial Stage. This may have partially provided the deflation source along with floodplain material exposed in the Derwent. The aeolian sands are likely to have been transported to the terrace in a similar manner to a climbing cliff-top dune (Jennings, 1967).

The textural characteristics of the original deposit have been modified by subsequent pedogenesis. However, the amount and distribution of silt in the sandsheet suggests the addition of windborn fines during deposition. This assumption is also supported by the relatively high proportion of silt in the Bridgewater deposit. Thus, the identifying characteristic of the Derwent sandsheets appears to be the presence of windborn fines, especially silt.

The Glenfield sandsheet overlies a complex series of locally derived slope deposits which are interbedded with a thin lens of aeolian sand. The colluvium represents multiple phases of slope instability prior to the deposition of the primary sandsheet. The interbedded sand lens indicates that slope instability was contemporaneous with at least minor phases of aeolian activity. The lens shows little or no evidence of profile development and is difficult to correlate with other aeolian deposits in the area. The sand could be derived by the deflation of alluvial sands exposed in the Jordan Valley sometime during the Upper Pleistocene, and may correlate with the older sandsheets at Lime Kiln Point and Red Gum.

Most, if not all, of the slope material at the site probably dates from the Last Glacial Stage, but this relationship cannot be demonstrated without absolute dating. The Glenfield sandsheet is locally mixed with the sediments of the uppermost slope deposit, a relationship which indicates that the initial phase of aeolian deposition coincided with the last major episode of hillslope instability at the site.

The long axis of the Glenfield sandsheet is roughly parallel to the prevailing westerly wind direction and the sands thin to the east. This orientation indicates a deflation source to the west in the lower Jordan Valley. A search of the present channel and floodplain sediments revealed no evidence of a potential source for the sandsheet as the modern alluvium consists of silts, clays and gravels. The alluvial sediments in the high and low terraces provide the only evidence for earlier aggradation phases in the valley.

The high alluvial sediments are very unlikely to be the primary source material for the sandsheet on two grounds. In the first case, the gross textural characteristics of the alluvium are entirely different from the sands which compose the aeolian deposit. In this respect the wind blown sands are unlikely to have been derived from the much finer alluvial material without inheriting some of its basic textural characteristics, especially silt. Secondly, the much stronger degree of soil development on the high terrace alluvium as compared with that on the sandsheet suggests that the two deposits are not of equivalent age.

The Glenfield basal sandsheet was most likely derived from the deflation of the low terrace alluvium and more specifically from the fine quartz sands near the base of the deposit. This relationship is further supported as the low terrace is not overlain by aeolian sediments of any age. The low terrace alluvium is graded below present sealevel, which indicates that alluviation and aeolian activity occurred sometime after the incision of the high terrace sediments and prior to the flooding of the Jordan Valley during the Holocene rise in sealevel. This relationship suggests that the period of deflation occurred during the Last Glacial Stage.

Sufficient evidence is not available to reconstruct the actual channel dynamics during alluvial deposition,but the abundance of alluvial sand in the low terrace may indicate sediment overloading in a braided system. The occurrence of these sands as either channel or floodplain material during aeolian activity suggests that catchment instability was due to a reduction in vegetation cover. Local slope instability is indicated by the colluvium which underlies and is interbedded with the sandsheet, and from the small scree deposits along the margins of the Jordan. These screes are not actively forming today and the debris most likely resulted from frost shattering in a colder climate.

The gradual transition from the basal sands to silts and clays in the upper portion of the lower terrace alluvium indicates a change in sediment load in the Jordan. This may have resulted from greater slope stability in the catchment associated with an increase in vegetation cover. In any event, the major phase of aeolian activity ended prior to the deposition of the silty alluvium as the sandsheet contains very little silt.

The lithologic variations observed between the basal sandsheets are most likely due to differences in the original parent material. The fine quartz sand in all three deposits is undoubtedly derived from reworked Triassic sandstones. However, the textural similarities between the Derwent sandsheets indicate that large amounts of fine alluvial material was being transported by the river at the time of deflation. In contrast, the relative absence of fines, especially silt, in the Glenfield sandsheet indicates the deflation of predominantly well sorted, sandy alluvium material.

These variations reflect differences in both drainage size and catchment lithology between the Derwent and Jordan river systems. In this respect the Derwent is a much larger drainage system than is the Jordan and a greater variety of source rocks are exposed in its catchment. The fine alluvium deflated from the Derwent was most likely derived from reworked Permian sediments, Jurassic dolerite and Tertiary basalt. Additional floodplain material could have been in the form of fine debris transported by the river from glaciated areas of the Central Plateau.

In contrast, the smaller Jordan catchment consists primarily of Triassic quartz sandstones with only small areas of Permian, Jurassic and Tertiary rocks. The lithologic and textural characteristics of the Glenfield sandsheet have been more strongly affected by a single type of source material than have the Derwent aeolian deposits. This factor is significant in explaining the differences in grain size distribution and pedogenesis observed between the sandsheets.

The presence of these and other sandsheets in the area does not provide direct evidence of the climatic conditions which prevailed during deposition. The sandsheets do indicate a phase of widespread groundsurface instability during the later part of the Last Glacial Stage. While fossil dunes in present humid temperate climates may indicate the occurrence of former arid conditions, this line of reasoning may be circular (Cooper, 1935). Aeolian sediments can and do accumulate in any type of climate provided that an adequate source of material is available for deflation and the groundsurface is locally unstable. The aeolian deposits therefore could be the result of a number of complex factors, some of which may be independent of climatic controls.

However, the stratigraphic relations and spatial distribution of the basal sandsheets support a marked reduction in vegetation cover on the exposed floodplain source areas in the Derwent and Jordan Valleys. The uniform, massive sedimentation pattern observed in the sandsheets, except for the coarse lenses near the base of the Bridgewater dune, suggest that the deposition sites may have had some growing vegetation during the periods of deflation, probably grasses. The orientation of the sandsheets indicates that strong west to northwesterly winds were primarily responsible for their deposition. The source-bordering position of the Old Beach and Bridgewater sandsheets in relation to the drowned valley of the Derwent support a glacial (low sealevel) age for the aeolian sediments. The major phase of aeolian activity which resulted in the deposition of the basal sandsheets is more consistent with marginal periglacial conditions, rather than with a warm, semiarid environment, and deflation most likely occurred in a cold, windy and seasonally very dry climate.

c. Relative Degree of Soil Development - Aeolian deposition at the principal sites was followed by groundsurface stability with soil development in the sands. Pedogenesis probably began during the later part of the Last Glacial Stage in response to a general climatic amelioration involving increased humidity and the thickening or increase of vegetation cover at the sites. Other environmental factors accompanying climatic change at this time could include a change in sediment load in the rivers, possibly due to an increase in vegetation cover, decrease in the intensity of westerly winds, and drowning of the floodplain source areas as a result of rising sealevels in the estuary.

All three profiles are truncated and only remnants of the original soils can be compared between the sites. Each profile shows relatively similar ped development, color and amount of cutanic material in the B horizon. These characteristics tend to be somewhat better developed in the Old Beach and Bridgewater profiles, but some degree of profile variation occurs at each site due to local differences in parent material and drainage conditions.

Figure 20 shows the clay and geochemical values determined at the type sections as a function of depth for the sandsheets. These data are useful in comparing the soil profiles and are an index of the relative degree of weathering between the sites.

In all cases the higher values of clay and oxides clearly define the B horizons formed in the sediments. The maxima also closely correspond with the greatest degree of structural development observed in the soils. However, there is considerable variation in the oxide concentrations between the sites. The data do indicate strong similarities between the Old Beach and Bridgewater profiles, especially in terms of extractable iron and sesquioxide amount and distribution. The similar high sesquioxide values suggest that these profiles are more nearly equivalent and that they are relatively more strongly developed than at Glenfield. In this regard, the structural differences in pedologic organization observed between the sites are strongly dependent on both clay content and oxide concentration.

The overall variations in profile development could have resulted from either differences in time of soil formation or in the suitability of the parent material for weathering. The greater degree of pedological organization of the Old Beach and Bridgewater profiles could indicate that these deposits have been weathered over a longer period, and are thus older than the one at Glenfield. However, there is no independent stratigraphic or geomorphic evidence to support this conclusion.

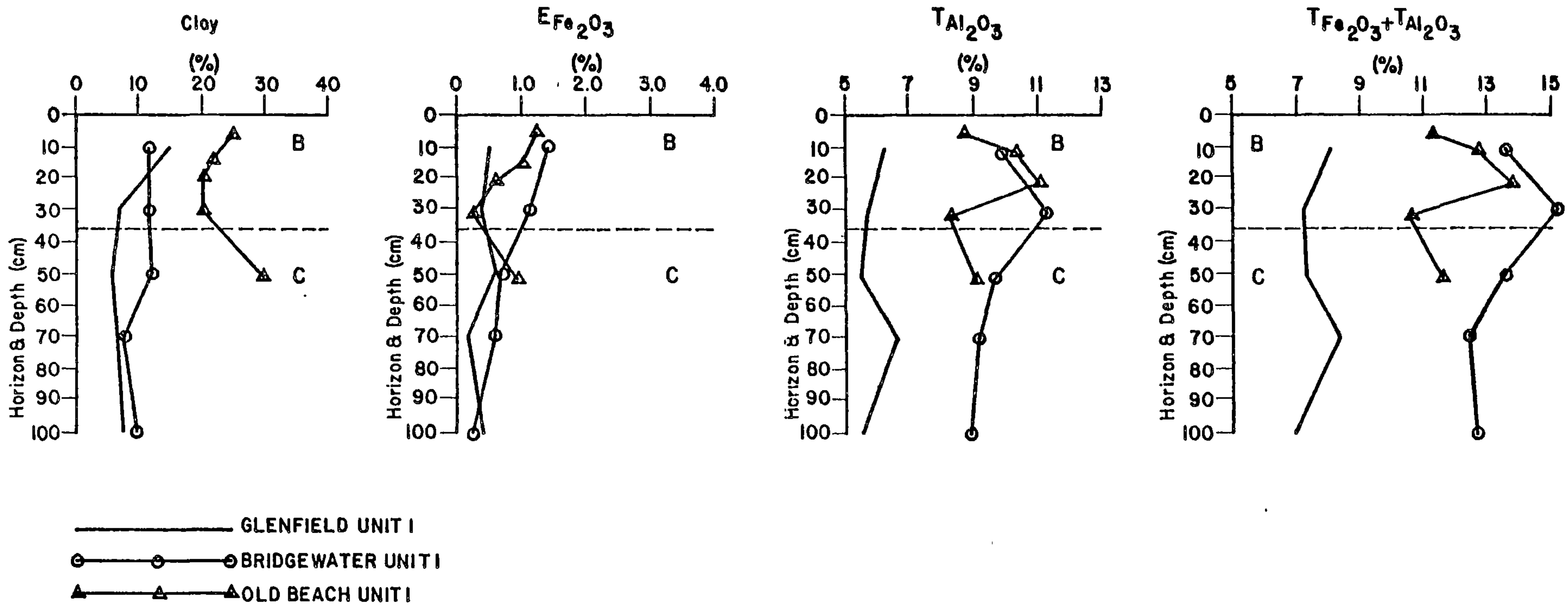


Figure 20. Clay and geochemical relations from the basal sandsheets (Unit 1) at Glenfield, Bridgewater and Old Beach

The local differences in profile development between the profiles are more likely due to the textural variations observed in parent material. The less well developed profile at Glenfield is formed on predominantly Triassic-derived quartz sands from the Jordan catchment. In this respect, the abundance of chemically inert, quartz sand in the deposit would tend to minimize the degree of profile development over time. This hypothesis is clearly supported by the relatively low values of iron and alumina in the Glenfield sandsheet. Given the nature and lithology of the source rocks, the most suitable materials available for weathering would have been sand-sized feldspar from the Triassic sediments, and isolated mafic minerals derived from the small areas of basalt and dolerite in the Jordan catchment.

As described earlier the Derwent sandsheets contain an abundance of fine material derived from a greater variety of source rocks. Direct weathering of the silt-sized material could account for the higher abundance of clay in these deposits. Also, the higher percentage of total iron in these sediments suggests a much larger proportion of inherited, basic igneous material than is present at Glenfield. The Derwent sediments would have more available iron and alumina prone to oxidation than would the relatively inert quartz sands at Glenfield.

The weakly developed and discontinuous cutanic material in these profiles is not consistent with the amount of clay in the B horizons, especially at Old Beach. This observation suggests that *in situ* clay formation was responsible for much of this fraction present in the solum (Oertel, 1968) and that little clay shift occurred during the development of the profiles. However, without micromorphological data there is no certain means of determining what proportion of the clay fraction in the profiles is illuvial, formed *in situ*, or is inherited from the parent material.

The large amounts of kaolinite in the B horizons at Old Beach and Bridgewater correspond with the iron and alumina maximas in these profiles. Conversely, montmorillonite is the dominant clay mineral in the B horizon at Glenfield. The clay mineral assemblages provide further evidence that the Old Beach and Bridgewater profiles are nearly equivalent, and that these soils are more strongly developed than is the one at Glenfield.

However, the mineralogical differences in clay between the sites are also more likely related to the nature and caliber of the parent material rather than the intensity of weathering or time of formation. In this respect the greater surface area of the fines incorporated in the Old Beach and Bridgewater deposits would tend to accelerate the process of mineral alteration. In addition, much of the fine material in these deposits was most likely derived from preweathered regolith debris, and this factor would strongly influence the type and amount of clay minerals formed during pedogenesis.

It is difficult to determine the precise routes of mineral alteration during weathering of the sandsheets. The clay minerals in each profile suggest the alteration of ferromagnesian minerals to montmorillonite with the partial release of ferrous iron in the B horizons and subsequent oxidation to the ferric state. This type of reaction is supported by the presence of montmorillonite and extractable iron maxima in the B horizons.

With increased leaching, the montmorillonite was most likely altered to kaolinite through the loss of calcium and magnesium. Kaolinite could also have formed by the direct alteration of potash feldspar (Loughnan, 1969). Illite and the interstratified clay mineral may be secondary products or remnants of incomplete reactions. These minerals could also have been inherited from the parent material as feldspathic minerals are readily available from the Triassic sediments.

The initial weathering of the sandsheets probably occured under relatively acid, leaching conditions given the permeability of the sands and the local drainage conditions. The double clay and iron oxide maxima at Old Beach could have resulted from differential weathering, and/or *in situ* formation of clay in both the B horizon and near the base of the C, where moisture was perched on the underlying estuarine sediments. As this profile is directly exposed to spray from the estuary, the addition of sodium salts may have caused lateral and vertical translocation of clay in a manner similar to the development of a solonetz profile (Stace, et. al, 1968). This process could explain the alkalinity of the soil and the cutanic material coating the archeological implements near the base of the deposit.

As the profiles are truncated, it is difficult to classify the type of soils formed on the sandsheets. The clay and extractable iron oxide maxima in the B horizons suggest that the profiles could have originally been podzolic soils of some nature. However, some degree of polygenesis is likely to be involved in the formation of the Old Beach and Bridgewater profiles due to the addition of salt spray from the estuary. The Bridgewater profile also contains free carbonate derived from the leaching and reprecipitation of shell material from the overlying midden.

If the profiles are remnants of podzolic soils, they would have most reasonably formed under subhumid or humid climatic conditions. This suggests that ground surface stability and profile development was produced by an increase in temperature, moisture and vegetation cover following the period of aeolian activity. Soil formation in the sandsheets must have occurred well into the Holocene before they were truncated as the profiles are too strongly developed to have been formed during a short weathering episode.

Archeological Data - The artifacts in the basal sandsheet at Old Beach provide the earliest known evidence of Aboriginal occupation in the lower Derwent Valley. The basal position of the implements indicates that human occupation was coeval with the initial formation of the dune. In the absence of radiocarbon control, the age of this occupation can only be assessed in terms of the relative stratigraphy. Aeolian deposition post-dates the truncation of the soil profile formed on the Interglacial estuarine sediments, and the occupation pre-dates development of the weathering profile in Unit 1. The minimum age for truncation of the weathering profile is about 5,800 radiocarbon years ago as suggested by the intrusive hearth dates.

As the floor of the Derwent-Jordan confluence area, the probable source of the sand, lies some 30 m below present sealevel, aeolian deposition is unlikely to have occurred after the sea began to flood this portion of the Derwent Valley some 11,000 to 9,000 BP (Shepard, 1961). Thus, the archeological evidence from Old Beach clearly indicates a late Pleistocene age for Man in southeastern Tasmania. The occupation of Old Beach appears to predate 9,000 to 11,000 BP, but by how long is unknown.

Only six lithic fragments have been recovered from the deposit. Sufficient evidence is not presently available to determine either the typological associations of the artifacts or the economy of the Aboriginal population. The apparent absence of hearths and other cultural debris within the sandsheet suggests that the site may have been occupied only for a short period of time.

Younger Aeolian Sequence - The stable phase during which the soil profiles were developed was followed by the truncation of the sandsheets and burial by younger aeolian deposits. The hearth date of 5,800 BP at Old Beach indicates a minimum age for the truncation of this deposit. The younger date of 1,960 BP at Old Beach from below Unit 2 also indicates that portions of the local groundsurface were exposed for a considerable time before burial, and that parts of the surface were disturbed and the soil truncated at different times. The date of 2,055 BP from the intrusive hearth at Glenfield indicates a minimum age for the truncation of this particular soil profile. Similarly, the weathering profile at Bridgewater is truncated by the Aboriginal shell midden with occupation beginning by at least 4,540 BP.

The aeolian sands which compose Unit 2 at Old Beach and Glenfield are considered to be litho-stratigraphic equivalents as they occupy the same relative stratigraphic position above the unconformity which truncates the underlying sandsheets. In addition, both units consist predominantly of fine quartz sand and each shows a similar degree of weak pedologic organization in the upper 10-15 cms.

The deposition of Unit 2 at each site indicates that a period, or more likely several periods of aeolian activity, due to habitat disturbance rather than climatic change, occurred between about 5,800 to after 2,000 BP. The deflation of these sands by westerly winds implies some reduction in the local vegetation cover synchronous with Aboriginal occupation. During this time range the estuary would have been flooded to near its present level and the adjacent confluence area could not have provided a deflation source for the younger aeolian sands at Old Beach. In the absence of an available floodplain source, Unit 2 at this site is most likely derived from the aeolian reworking of the underlying sandsheet. This conclusion is supported by the textural similarity of the Unit 2 sands with those which form the basal sandsheet.

Unit 2 seems to have originated by the local disturbance and contemporaneous deflation of the A horizon formed in the underlying soil profile. Some of the sand could have been derived from the reworking of the B horizon after the A horizon had been eroded. The marked absence of silt or clay in Unit 2 indicates that any fine material was far removed during deflation.

Unit 2 at Glenfield is derived from the disturbance and aeolian reworking of the underlying sandsheet in a manner similar to that which occurred at the Old Beach site. This conclusion is supported by the close textural similarity between the sands which form Unit 2 and those of the basal sandsheet. This relationship is clearly shown in terms of the similar modal grain size of the quartz sands which compose the two units. The relationship between these aeolian deposits is further demonstrated by the absence of a fine sandy floodplain source for Unit 2 in the Jordan channel. The Unit 2 sands are most reasonably derived from the redeposition of the A horizon formed in the underlying sandsheet during a period of instability at the site. The basal date of 2,055 BP provides a maximum age for Unit 2 at this location. The date of 1,245 BP near the surface of the unit gives an approximate limit to the period of deposition.

The shell midden at Bridgewater unconformably overlies the truncated sandsheet. The matrix of the midden consists of fine quartz sand which is texturally similar to that of the sandsheet. The sands which compose the midden were most likely derived by the reworking of the surface horizons of the underlying soil profile through Aboriginal disturbance of the local groundsurface. Consolidation of the redistributed sands was enhanced by the presence of organic matter and carbonate as cementing agents.

The field evidence and laboratory analyses of the aeolian sediments suggest that the formation of the secondary aeolian deposits resulted from localized disturbance at each site. The evidence indicates that the activities of Aboriginal Man were largely responsible for the surface instability. This conclusion is further supported by the archeological evidence associated with the unconformities and secondary aeolian deposits, and from the absence of floodplain sources for the sands which formed these units.

The formation of Unit 2 at Old Beach and Glenfield is associated with vegetation burning and subsequent groundsurface disturbance caused by the Aboriginals occupying the sites. Removal of the plant cover appears to have exposed a weakly structured A horizon of the underlying soil profiles, which would have been highly susceptible to wind and water erosion. The slopewash facies of Unit 2 at Old Beach is present in a small gully downslope from a large concentration of hearths and probably accumulated as a result of Aboriginal disturbance upslope.

Burning of the vegetation cover may have been accidental or intentional. Ethnographic information describes random burning of the local vegetation by the Aboriginals apparently for amusement (Jones, 1968). In other accounts the Tasmanians used fire as a conscious and effective tool in hunting (Jackson, 1965). Additional pressure on the local environment may have resulted from vegetation clearing for fuel. The effects of a small group of intensive hunters and gatherers on an easily eroded groundsurface would quickly result in localized instability. The aeolian redistribution of the surface horizons need only require intermittent human disturbance and prevailing westerly winds.

The pattern of local disturbance and landform modification resembles the large scale changes in the environment caused by Huron settlement and vegetation clearing in eastern Canada (Cruickshank and Heindenreich, 1969). These authors found that the A and portions of the B horizons of podzols were thoroughly disturbed after 10 to 15 years of human land use. The truncation of the soil horizons was thought to have resulted from wind and sheetwash erosion following vegetation removal. Similar patterns of erosion caused by prehistoric human activity have been recorded from Indian sites in Mexico and California (Cook, 1965).

The dated hearths from Old Beach indicate that a phase of Aboriginal occupation had begun in this area by at least 5,800 BP. Occupation of the Derwent Valley by this time is supported by a basal date of 5,220 ± 110 BP (ANU-1090A) and 5,890 ± 90 BP (ANU-1090B) on shell carbonate and charcoal from near the base of a midden in Shag Bay some 5 km south of Old Beach along the east side of the estuary (Wallace, pers. comm.).

The distribution of these sites indicates that Aboriginal occupation was established about the time that the sea reached its present level (Flint, 1971). Aboriginal occupation gradually extended up the Derwent Valley as the sea progressively flooded the estuary. This conclusion is supported as the oldest known middens in southeastern Tasmania are found along the present coastline.

The dated hearths from Old Beach could indicate a relatively continuous period of Aboriginal occupation at the site from mid-to late Holocene time. The presence of shellfish remains, flaked implements and grinding tools indicates a mixed economy based on both estuarine and terrestrial resources. The abundance of exposed hearths at the site cannot be used as a means of estimating population size at any given time as the two dated hearths are of significantly different ages.

The hearths and cultural material associated with Unit 2 at Glenfield indicate a period of Aboriginal occupation lasting some 800 radiocarbon years. The vertical distance between the dated upper and lower hearths is about 1 m, giving a rate of deposition of about 0.125 cms/radiocarbon year. This assumes a uniform rate of dune accumulation which is unrealistic, but the value gives a rough estimate of the intensity of human activity at the site and its effect on the local environment.

The flakes, implements and grinding tools within the unit, or in probable association, indicate a hunting and gathering economy. The single mussel shell hearth found in association with the unit suggests some reliance on the estuary as a source of food. The lithology of the stone implements indicates a local source from nearby quarries as chert-hornfels and quartzite are readily available from the dolerite contact with the Permian and Triassic sediments. Quartzite is also available from the Jordan channel and from the surface of the high alluvial terrace. Material for grinding stones is readily available from the dolerite and basalt outcrops near the site.

The small flake scatters on the surface of the basal sandsheet indicate the local manufacture of implements. The surface distribution of grinding stones and flaking floors support the separation of areas of cultural activity as noted by Lourandos (1970) at Crown Lagoon. However, the apparent distribution of surface artifacts at Glenfield could be influenced by differential artifact collection by the Europeans following site abandonment.

Glenfield appears to have been a transition site used during Aboriginal migrations from the estuary to inland areas and may have only been occupied intermittently by small groups. Ethnographic evidence indicates that migration was relatively common and possibly occurred seasonally in response to movements in game animals (Lourandos, 1970).

The occupation of the site may have been related to a number of local environmental factors. The site is near the Jordan River which would have attracted game animals and the area would be an opportune hunting location. The dune is on a gentle north-facing hill and the high reflectivity of the sands would provide warmth. The local downslope ponding of water on the relatively impermeable basal sandsheet and underlying slope deposits would insure at least a seasonal supply of water at a shallow depth.

The Bridgewater midden is located directly adjacent to the Derwent estuary and the rocky dolerite shore must have provided an ideal habitat for mussels. The scarcity of oyster shells in the midden indicates that these shellfish were not widely available at the time of occupation, possibly due to silting of the estuary. Alternatively, the abundance of mussel could be related to a local food preference of the Aboriginal group. The absence of flaked implements in the midden suggests an exclusive estuarine orientation for food; a feature reported from other shell middens in Tasmania (Jones, 1967; Lourandos, 1970).

Charcoal fragments and small concentrations of ash in the midden are remnants of fires used in cooking. At midden sites the shellfish were apparently roasted on small fires and eaten as quickly as they were ready (Lourandos, 1970). It is impossible to estimate the size of the Aboriginal population or the length of time the midden was occupied. The midden is relatively thin, although it covers an extensive area along the Derwent. This could indicate either a relatively short period of Aboriginal occupation by a large population or more likely, continuous occupation for a relatively longer period by small groups.

The deposition of Unit 2 at Glenfield and Old Beach was followed by local stability and weak pedogenesis. The red hue in the upper 10-15 cms of these units indicates a gradual cessation of aeolian activity with oxidation of iron compounds. The deposits show no textural differentiation and contain very little inherited silt or clay. As the sands are derived from the surface horizons of the underlying soils, the degree of profile development is probably more dependent on the depleted nature of the parent material, rather than the intensity of weathering or duration of stability.

Local stability and weathering most likely resulted from the abandonment of the sites, although the reasons for this are unknown. Stability at Glenfield apparently lasted for about 1000 radiocarbon years as suggested by the date of 210 BP from the hearth overlying Unit 2. The hearth and its associated organic lens represents a local surface of Aboriginal occupation and rehabitation of the site after an apparent cultural hiatus of about 1000 years. The lens is probably derived from the partial redistribution of the underlying sands of Unit 2 and could have accumulated during a visit of short duration by a small group of Aboriginals.

The date of 210 BP indicates occupation somewhat before or at the time of European settlement of the area. Tasmania was first sighted by Abel Tasman in 1642 and the island was visited several times by Europeans over the next 200 years. However, the full impact of European culture and the extinction of the Tasmanians did not begin until the first English colony was established in Hobart in 1804. European occupation of the Bridgewater-Glenfield area began about 1810 by free settlers and the resulting land use would have quickly modified the natural environment. Chronologically, the Glenfield upper hearth may represent the final period of Aboriginal occupation of the site prior to abandonment in the face of European contact.

At Glenfield and Old Beach Unit 2 is truncated by the sands which compose Unit 3. At Glenfield this unit accumulated during the period of

European occupation as indicated by the date of 210 BP from the organic lens which directly underlies the deposit. A European origin is further indicated by the presence of *Taraxacum* pollen in the deposit at both Glenfield and Old Beach. Unit 3 is most likely a plow layer resulting from the disturbance and redeposition of the Unit 2 sands. The absence of implements and hearths in this unit suggests abandonment of the site prior to deposition.

The surface of Unit 3 at Glenfield and Old Beach, and the shell midden at Bridgewater are truncated, and are unconformably overlain by the disturbed surface sands. These were formed by the aeolian redeposition of all the underlying units at the sites and have resulted from increased European modification of the landscape over the last 150 years. The sands have accumulated under the influence of westerly winds and represent the effects of heavy grazing and repeated attempts at land clearance.

The deposition of the Unit 4 sands at Glenfield has also been influenced by local sand quarrying. Large scale excavations and disturbance of the sandsheet began in the 1930's during the construction of a Hobart bank and sand is still being removed for cement making. This site allows some comparison of the land use intensity between the Europeans and the Tasmanian Aboriginals. In this respect nearly 800 radiocarbon years of Aboriginal occupation were required to produce Unit 2 which is up to 1.5 m thick. The sands which have accumulated in the last 150 years as a result of European disturbance of the site locally exceed 2.5 m in thickness.

CHAPTER 7

INTERPRETATION AND CORRELATION OF DEPOSITS FROM THE ADJACENT AREA

The numerous small sandsheets and dunes exposed in the lower Derwent Valley and elsewhere in southeastern Tasmania provide evidence for multiple periods of aeolian activity in the past. In the lower Derwent Valley, many of the aeolian units are closely associated with the alluvial fan and slope deposits, and the sequences imply climatic conditions significantly different from those which prevail today, especially those critical environmental factors which limit vegetation cover and increase the potential for mechanical weathering on the upper slopes of the valley.

Paleoenvironmental Interpretation - The local stratigraphic succession contains two sets of aeolian sandsheets and dunes separated by periods of widespread slope erosion and alluvial fan deposition. In the lower Derwent Valley, the sandsheets and dunes have been deposited by strong west to northwesterly winds and border alluvial source areas in the river now drowned by the sea. The aeolian sediments either overlie or are stratified within the alluvial fans, and some are found underlying slope deposits exposed near river level. These relationships indicate widespread slope instability at or near the times of aeolian activity, concurrent with strong westerly winds and a reduction in vegetation cover, particularly on the upper slopes and the exposed floodplain source areas in the valley.

The original extent of the older sandsheets at Red Gum and Lime Kiln Point cannot be determined, but the aeolian sediments were probably derived from the deflation of sandy floodplain material exposed immediately upstream from each site along the Derwent. The younger, fine sand to silt sheets between New Norfolk and Bridgewater appear to have been discontinuously deposited across interfluves and fan surfaces in a manner similar to the Canterbury, New Zealand loess deposits as described by Ives (1973), but on a much smaller scale. The Derwent aeolian deposits are thickest on the leeward sides of the interfluves, but the original depositional pattern is difficult to reconstruct as many of the thin sheets may have been eroded or buried.

The dune at Malcolms Hut is derived from the deflation of predominantly sandy material, probably exposed on the surface of the adjacent alluvial fan; however, the exact source of the aeolian material has not been identified. This dune was deposited by high intensity, westerly winds as indicated by the very coarse grains and granules throughout the deposit, and blankets the surface of an older, strongly weathered alluvial fan. The date of 15,740 BP gives an approximate age for the period of aeolian activity as the charcoal used in the determination was collected about 1.5 m above the base of the dune. The well-defined subhorizontal bedding in the deposit indicates intermittent cycles of aeolian activity during formation of the dune.

The associated alluvial fan and slope deposits provide additional information concerning the environmental conditions which prevailed at or near the times of aeolian activity. A brief evaluation of these deposits is useful in establishing a broader paleoenvironmental framework by which to interpret the climatic significance of the aeolian sediments.

The alluvial fans in the lower Derwent Valley are essentially inactive in the present environment, and the adjacent slopes are vegetated and appear stable, except where disturbed by the activities of Man and grazing animals. Modern slope stability indicates that the processes responsible for both the production and transportation of colluvial and fan debris in the past are now operating at a low intensity, if at all. The caliber and extent of the debris supports an interpretation of widespread and prolonged slope instability with widespread catchment erosion during fan deposition. The accumulation of these deposits implies a marked reduction in vegetation cover, especially on the upper slopes of the valley. A low vegetation density and non-forested environment during fan deposition is further indicated by the absence of woody plant remains in both the fan and slope deposits. Periods of extreme cold and/or drought are the most likely climatic conditions to have caused widespread catchment erosion and a reduction in vegetation cover in the valley.

The extensive mantles of periglacial solifluction material on the upper slopes of the valley provide conclusive evidence of former cold climate conditions in the area (Davies, 1967). Much of the coarse, angular fan debris is similar to that which composes the solifluction deposits; a relationship which strongly suggests that the fans were depositional sites for the frost-shattered debris produced on the upper slopes. This conclusion can be demonstrated as some of the alluvial fans can be traced laterally into solifluction material exposed at higher elevations in the valley.

The above considerations indicate that the fans are cold climate phenomena associated with multiple periods when frost action caused physical fragmentation of rock on the upper slopes of the valley. In contrast, there is no evidence to suggest that the fans accumulated in a warm, semiarid environment. While a detailed analysis of the periglacial deposits lies outside the scope of this dissertation, there seems to be sufficient evidence to indicate a genetic relationship between the solifluction debris and the alluvial fans. Given the evidence of widespread glaciation in the Highlands of Tasmania (Derbyshire, 1972), the major periods of solifluction activity and fan deposition most likely occurred during cold phases accompanying one or more glacial stages. A glacial (low sealevel) age for the fans is further suggested because these deposits are graded below present sealevel in the estuary.

Each set of aeolian, alluvial fan and slope deposits recorded in the valley probably forms a continuous series deposited during any cold climate phase of significant magnitude and/or duration. During cold phases, most likely corresponding to glacial advances in the Tasmanian highlands, the climate of the lower Derwent Valley was probably strongly seasonal with relatively cold winters and short, cool summers. This conclusion is supported by the modern climatic data from the area, particularly the frost record from Mt. Wellington, which suggest that a reduction in mean annual temperature could greatly increase the frequency of frost weathering on the upper slopes and limit the vegetation cover. Given colder temperatures, most of the winter precipitation would be in the form of snow, and spring melts may have provided most of the water to transport the soliflucted debris from the upper slopes to the sites of alluvial fan deposition in the valley.

All primary aeolian deposits in the lower Derwent Valley, including those at Glenfield, Bridgewater and Old Beach, are derived from floodplain material once exposed in the river valley, and occupy lee positions relative to the prevailing westerly wind direction. The absence of exposed floodplain areas in the present estuary indicates that the periods of deflation occurred during glacio-eustatic low sealevels and were characterized by high intensity, westerly winds. Some reduction in local vegetation cover must have occurred at the same time to allow saltation of sand from the alluvial source areas to the sites of aeolian deposition. Aeolian activity could have occurred at any time of the year, but most likely coincided with relatively dry periods when the river contracted to one or more channels exposing alluvial sands and silts. Since the modern wind data from New Norfolk (Table 3) indicate that the highest potential for sand transporting days is from late spring through summer, it is likely that the periods of aeolian activity in the past occurred during these seasons when the floodplain source areas were dry enough to be eroded by the wind.

The paleosols formed on each of the aeolian units are important stratigraphic markers and reflect groundsurface stability and weathering between the periods of alluvial fan and slope deposition. Stability and weathering most likely resulted from warmer environmental conditions of unknown duration and/or magnitude. As temperatures increased during these periods, the climate of the lower Derwent Valley probably became subhumid to humid to facilitate oxidation and textural development in the soil profiles. Higher temperatures would limit the potential for frost weathering on the upper slopes, and lead to greater surface stability and an increased vegetation cover throughout the valley.

In summary, the evidence from the lower Derwent Valley indicates that the periods of aeolian activity, along with alluvial fan and slope deposition, occurred during cold, windy and seasonally dry climates, most likely corresponding with one or more periods of glaciation in the highland areas of the West. Warmer intervals, characterized by surface stability and weathering of the aeolian deposits, could have occurred during either interstadial or interglacial periods In this respect, the type of pedologic alteration on many of the sandsheets and dunes suggests a climate not markedly different from that of today.

CORRELATION OF THE SEQUENCES

The double set of aeolian and alluvial fan deposits in the lower Derwent Valley presents a complex problem of correlation. The date of 15,740 BP from the dune at Malcolms Hut indicates that the last major phase of aeolian activity occurred during the later part of the Last Glacial Stage. This date is significant as it supports earlier conclusions as to the probable ages of the principal sandsheets at Glenfield, Bridgewater and Old Beach. Unfortunately, radiocarbon dates are not available for any of the other aeolian and alluvial fan deposits from the region, and their age relations can only be tentatively assessed from indirect geomorphic and stratigraphic evidence.

Several hypotheses can be advanced to explain the stratigraphic position of these deposits, and as shown in Table 8, the sequences could have accumulated during either a single or double cycle of major glaciation. The relative sequence of events is believed to be valid; however, insufficient evidence is presently available to determine whether a restricted single glacial stage or an expanded double glacial stage cycle

TABLE 8

TENTATIVE LATE QUATERNARY SEQUENCE FROM THE ADJACENT SITES IN THE LOWER DERWENT REGION

A. SINGLE GLACIAL STAGE HYPOTHESIS

GEOLOGIC AGE		RED GUM	LIME KILN POINT	SITE A	SITE B	MALCOLMS HUT
HOLOCENE			Slope Deposits			Surface Sands
LAST GLACIAL STAGE	LATE	Alluvial Fan	Aeolian Sandsheet Alluvial Fan	Slope Deposit Aeolian Sheet	Upper Aeolian Sheet Lower Aeolian Sheet Alluvial Fan	Aeolian Sandsheet (15,740 BP)
	MIDDLE					
	EARLY	Aeolian Sandsheet Alluvial Fan	Aeolian Sandsheet Alluvial Fan	(?)	(?)	Alluvial Fan (?)

B. DOUBLE GLACIAL STAGE HYPOTHESIS

GEOLOGIC AGE	RED GUM	LIME KILN POINT	SITE A	SITE B	MALCOLMS HUT
HOLOCENE		Slope Deposits			Surface Sands
LAST GLACIAL STAGE	Alluvial Fan (?)	Aeolian Sandsheet Alluvial Fan (?)	Slope Deposit (?)	Upper Aeolian Sheet (?)	Aeolian Sandsheet (15,740 BP) (?)
LAST INTERGLACIAL STAGE					
PENULTIMATE GLACIAL STAGE	Aeolian Sandsheet Alluvial Fan	Aeolian Sandsheet Alluvial Fan	Aeolian Sheet Alluvial Fan	Lower Aeolian Sheet Alluvial Fan	Alluvial Fan (?)

Soil

is correct. Moreover, the exact correlation may ultimately prove to be somewhat more complex than the alternatives outlined here. Hence, the correlations are tentatively adapted as multiple working hypotheses, and each should serve as a comparative and interim base on which future research may be conducted.

The Lower Aeolian - Alluvial Fan Sequence - The oldest aeolian deposits known from the lower Derwent Valley are the sandsheets which separate the alluvial fan sequences at Red Gum and Lime Kiln Point. These sandsheets are considered equivalents because they occupy the same relative position between two distinctly separate episodes of alluvial fan deposition. In addition, these aeolian units are texturally similar and each shows nearly the same relative degree of soil profile development.

In contrast, all other aeolian deposits known from the area either overlie fans with surface expression or they are buried by younger slope materials. This suggests that the upper aeolian units in the valley are more closely related to the last period of alluvial fan deposition than the first. In addition, the relative degree of soil development on the upper aeolian deposits is less than that observed on the lower sandsheets, regardless of differences in the original parent material.

Without further evidence, the age of the lower sequence of aeolian and alluvial fan deposits cannot be conclusively demonstrated. However, there are several lines of indirect evidence which could indicate that the lower sandsheets and fans were deposited during the early part of the Last Glacial Stage.

First, the evidence from coastal areas in southeastern Tasmania demonstrates the widespread occurrence of marine, estuarine and fluvial sediments of probable Last Interglacial age deposited up to 20 m above present sealevel (Colhoun, pers. comm.; Goede, pers. comm.). In the lower Derwent Valley, deposits of this general age probably include many of the high level sediments at various elevations above river level, as well as those described from Bridgewater, Old Beach and in the lower Jordan Valley.

If the lower sequence of sandsheets and fan deposits at Red Gum and Lime Kiln Point accumulated during the Penultimate Glacial Stage as suggested in Table 8b, it is likely that these deposits would have been buried by Last Interglacial fluvial or estuarine sediments with well developed paleosols. In fact, none of the exposed alluvial fans in the valley contain either estuarine or Derwent-derived, fluvial sediments of any age. Until such definitive stratigraphic evidence is found to support a Penultimate Glacial age for the lower sequence of deposits, it is reasonable to suggest that all of the aeolian and fan deposits in the valley post-date the Last Interglacial Stage.

Second, given the implied environmental relations between the periglacial and alluvial fan deposits, several infinite radiocarbon dates on solifluction and slope material from the region tend to support an early Last Glacial age for the lower sandsheets and alluvial fans. These determinations are as follows:

1) a date of >40,000 BP (I-8155) on charcoal from a truncated and buried reddish soil on solifluction debris from the upper slopes of Mt. Wellington (Wasson, pers. comm.);

2) a date of >37,000 BP (SUA-309) on carbonized wood in a solifluction deposit exposed at the surface near Gellibrand Point on the South Arm Peninsula (Colhoun, pers. comm.);

and 3) a series of five infinite dates (SUA-347, 348, 349, 389 and 391) from a complex succession of slope deposits overlying a marine beach of probable Last Interglacial age at Remarkable Cave on the Tasman Peninsula (Colhoun, pers. comm.).

From this evidence, it could also be argued that both the Gellibrand Point and Mt. Wellington deposits date from the Penultimate Glaciation, and that those from Remarkable Cave have no particular climatic significance. However, the solifluction deposit from Gellibrand Point offers strong evidence of a periglacial environment at or near present sealevel during the early part of the Last Glacial Stage. This conclusion is further supported because the deposit is exposed at and below present sealevel, and incorporates weathered regolith material derived from a strongly weathered paleosol developed on marine sediments of probable Last Interglacial age (Colhoun, pers. comm.). In addition, the solifluction debris is neither modified, nor is it overlain by marine sediments indicating a sealevel any higher than present.

The Mt. Wellington solifluction deposit could possibly be a remnant from the Penultimate Glacial Stage; however, it seems unlikely that the debris would survive for this length of time on the steep upper slopes through at least two highly erosive episodes of periglacial activity. This consideration only partially supports the single glacial stage hypothesis to explain the lower aeolian and alluvial fan sequence in the valley. Similarly, the climatic interpretation of the Remarkable Cave deposits is uncertain, and these slope units may only relate to local slope instability without special environmental significance. However, the mobilization of slope material at this site was broadly coincidental with the period of periglacial activity recorded at Gellibrand Point during the early part of the Last Glacial Stage.

Finally, the relative degree of soil development on the truncated sandsheets at Red Gum and Lime Kiln Point favors a Last Glacial age for the lower sequence of deposits. In general, these profiles appear to be relatively less developed than are those formed on the fluvial, estuarine and marine sediments of probable Last Interglacial age. This tentative interpretation is based primarily on the greater degree of ped development, extent and thickness of cutans, and thickness of the B horizons observed on the high level sediments as compared with the buried sandsheets. In contrast, the profiles on the buried aeolian units are relatively better developed than are the paleosols on the principal sandsheets at Bridgewater, Old Beach and Glenfield.

The differences in gross pedological development between these paleosols does not necessarily demonstrate that the lower aeolian and alluvial fan deposits formed during the early part of the Last Glacial Stage. However, the relatively greater degree of profile development on the sediments of probable Last Interglacial age suggests that these soils have been weathered for a considerably longer period than have those on the lower sandsheets. On the basis of this criterion, the sandsheets at Red Gum and Lime Kiln Point could be younger than the high level, fluvial, estuarine and marine sediments, and post-date the Last Interglacial Stage.

The above arguments do not conclusively prove that the lower aeolian and alluvial fan sequence in the lower Derwent Valley dates from the early part of the Last Glacial Stage, and not the Penultimate Glaciation. However, the local evidence clearly indicates that an episode of periglacial activity occurred during an early stadial period of the Last Glacial Stage. This cold stage appears to have been of sufficient magnitude and/or duration to cause the deposition of soliflucted debris in certain locations at and below present sealevel. Although the vegetation distribution at this time may have been controlled by aridity as well as temperature, a climatic change of this magnitude could have lowered the present tree line by as much as 1000 m. Given these paleoenvironmental implications, it is quite possible that the lower sequence of sandsheets and alluvial fan units in the valley could have been deposited during this stadial period. If this correlation is correct, then weathering of the lower sandsheets most likely occurred during a warmer, and probably more humid, interstadial period of the Last Glacial Stage.

The Upper Aeolian - Alluvial Fan Sequence - Weathering of the lower sandsheets was followed by a period of renewed slope instability during which the second generation of aeolian and alluvial fan deposits were formed. Reactivation of the fans probably resulted from similar environmental conditions to those which prevailed during the deposition of the lower fan sequence; a second, major climatic oscillation to cold, dry conditions. This change was probably contemporaneous with the re-establishment of glaciers and ice caps on the West Coast ranges and Central Plateau.

The only radiocarbon dates on periods of fan deposition in Tasmania come from Rocky Cape on the northwest coast. Wood from an alluvial fan has been dated in a sequence and provides a minimum age of 24,000 $\pm$ 1,030 BP (GaK-5155) and a maximum age of 33,240 $^{+5,610}_{-3,270}$ BP (Gak-5691) for deposition (Colhoun, pers. comm.). By comparison, these dates are somewhat earlier than the maximum of the last glaciation dated at less than 23,640 ± 1,030 BP (GaK-5597) at the Henty Bridge site (Colhoun, pers. comm.). It is apparent from the dates at Rocky Cape that the period of periglacial activity and fan deposition in this area began at least 10,000 radiocarbon years before the maximum of the last glaciation.

If correlation with the Rocky Cape fan is possible, the dates could provide an approximate time range for the deposition of many of the alluvial fans in the lower Derwent Valley, and establish their stratigraphic position in the second half on the Last Glacial Stage.

The evidence from the lower Derwent area indicates that the later part of this period of fan deposition was broadly contemporaneous with a second major phase of aeolian activity. This conclusion is supported by the incorporation of fan gravels in the lower aeolian sheet at Site B in the lower Derwent Valley, and by the occurrence of aeolian units locally buried by slope debris near river level (Site A, see Figs 3, 18 and 19). Further support for a late Last Glacial age for these sandsheets is given by the date of 15,740 BP from the dune at Malcolms Hut.

Absolute dating of the upper aeolian units in the lower Derwent Valley is not available. However, aeolian deposition in each case was dependent on the availability of a floodplain source in the emerged valley of the Derwent, the caliber and amount of the alluvium, and the condition of the local vegetation cover. In the case of available floodplain source areas, the base of the postglacial (?) estuarine fill in this portion of the valley is between 15 - 22 m below present sealevel. A comparison of worldwide sealevel curves with this area suggests that most of the potential floodplain source areas would have been drowned by about 11,000 BP

(Milliman and Emery, 1968; Shepard, 1961). As with the Bridgewater and Old Beach sandsheets, this general time only provides a minimum age for this period of aeolian activity, and the deflation of floodplain material from the emerged valley could have occurred throughout the later part of the Last Glacial Stage.

The extent of aeolian deposition in the valley would also be controlled by the nature and amount of floodplain material available for deflation, as well as the type and density of the vegetation cover. A change in sediment load in the river, concurrent with drowning of the floodplain source areas and a decrease in the intensity of westerly winds, would greatly reduce the potential for aeolian erosion to occur. A marked reduction in sediment load may have resulted from greater slope stability in the Derwent catchment and those of its major tributaries. Stability was most likely caused by an increased vegetation cover, especially re-forestation of the adjacent slopes and interfluves, due to an amelioration of climate beginning at the end of the Last Glacial Stage.

The soil profiles formed on the upper sequence of aeolian deposits at Lime Kiln Point, Site B and Malcolms Hut indicate that stability and weathering follow the last period of slope and/or alluvial fan deposition at each site. The stratigraphic position of many of these soils in relation to the alluvial fan deposits suggest that groundsurface stability and weathering began by at least late glacial times and continued into the Holocene. As stated earlier, weathering of the upper sequence of sandsheets and dunes most likely occurred in a climate characterized by warmer temperatures with increased humidity.

The buried soil on the fine loessic material at Site A is minimally weathered and shows no evidence of profile differentiation. This suggests that only a short period of stability occurred before burial by the overlying slope deposit. There is no independent evidence to suggest that this thin unit was deposited during the first period of aeolian activity, as represented by the buried sandsheets at Red Gum and Lime Kiln Point. The absence of a distinct soil profile on the Site A deposit suggests that such a correlation is unlikely and the unit was probably deposited during the later part of the Last Glacial Stage.

The truncated paleosol on the lower aeolian sheet at Site B in the Derwent Valley indicates that a brief period of stability and weathering occurred near the end of alluvial fan deposition and prior to the accumulation of the upper sheet. The buried soil, while developed on a finer loessic parent material, is less strongly developed than are the older paleosols on the sandsheets at Red Gum and Lime Kiln Point. The gross differences in profile characteristics between these sites, especially in terms of the apparent degree of textural enrichment and cutan development in the B horizons, suggest that the Site B paleosol is much younger than those at Red Gum and Lime Kiln Point and was weathered for a shorter period of time. By comparison, the Site B profile is more similar to those developed on the Bridgewater and Glenfield sandsheets.

The upper aeolian unit at Site B could have been derived from either aeolian reworking of the lower sheet, or a renewed supply of fine material deflated from the Derwent floodplain source area; or both. The absence of gravel in this unit suggests that this area of the fan was stable during the phase of aeolian activity. However, the adjacent interfluve to the west was most likely sparsely vegetated to permit deflation. The profile formed on the upper aeolian sheet, characterized by the accumulation and translocation of organic matter in the A horizon with precipitation of free carbonate in the C, has the general appearance of a minimal prairie soil. The profile is probably actively forming in the present environment, and its characteristics reflect the subhumid, semi-continental climate of the lower Derwent Valley.

Aeolian deposition at Malcolms Hut was followed by podzolization in the sands. Podzols can and do form in a variety of climatic conditions (Fitzpatrick, 1971), and this type of profile is probably more dependent on the siliceous nature of the parent material than other environmental variables, such as time of formation or intensity of weathering. Pedogenic alteration of the deposit could have occurred rapidly once a stable ground-surface was established at the site. Alternatively, this soil could have formed more or less continuously over the entire period until European disturbance of the site; it is not possible to further qualify this relationship without additional research.

Because of these reservations, this soil profile, while dated and important, cannot be used as the sole basis of comparison with other soil-stratigraphic units in the region. However, the podzol at Malcolms Hut is probably equivalent to the weak podzolics formed across the surfaces of many of the alluvial fans in the Derwent, as well as the soils developed on the upper sequence of aeolian deposits, including those at Old Beach, Glenfield and Bridgewater.

Summary - The conclusions about the interpretation and correlation of the deposits in areas adjacent to the principal sites are tentative. As the older part of the sequence lies beyond the range of radiocarbon dating, any scheme of correlation must rely on similarities of morphologic, lithologic and pedologic evidence to establish relationships between deposits widely separated in space and/or time. Because these relationships have not been studied in detail, the correlations presented here can only serve as an interim, comparative basis which may aid future research.

The relative stratigraphic succession in the lower Derwent Valley indicates two distinct periods of alluvial fan and aeolian deposition separated by an interval of surface stability and weathering. While the sequences could have accumulated during two separate glacial stages; the first during the Penultimate Glaciation and the second at or near the maximum of the Last Glacial Stage, several lines of evidence suggest that the entire succession is more likely to have been formed during two major stadials and one interstadial period within the last glaciation. Until such time as additional local and regional evidence is available, the correlation of these deposits, especially the lower sequence of sandsheets and alluvial fans, will remain uncertain.

PART III

MIDLANDS SITES

CHAPTER 8

CROWN LAGOON

This chapter considers the field evidence from Crown Lagoon, a small lake basin with lunette dune, located in the southeastern portion of the Midlands. The first section is a description of the lacustrine and associated aeolian sediments found in and around the basin; the second considers the pollen evidence obtained from a short core in the upper portion of the lacustrine sediments; and the third section deals with the stratigraphic and archeological relations of the redistributed aeolian sands on the surface of the lunette.

I. LACUSTRINE-AEOLIAN SEQUENCE

Crown Lagoon, located near the settlement of Lemont, is one of the numerous small lake basins in the Midlands and eastern coastal region of Tasmania (Figure 4). The basin lies on a plateau surface between 380-450 m above sealevel which separates the rugged Eastern Highlands from the Midlands Graben. The plateau may be an uplifted erosion surface (Davies, 1959a). It is dissected by streams, and broad flat topped erosion remnants and low basins occur throughout the area. West and north of the lagoon, the plateau level is interrupted by rectilinear ridges, or tiers, which have an average elevation of between 550 and 620 m. The ridges are separated by relatively broad straight valleys that contain very small, ephemeral streams.

Crown Lagoon is an irregularly shaped, dry lake basin of about 200 hectares at an elevation of about 375 m (Figure 21; Plate 29). The small lunette which rises to about 7 m above the dry lake floor is located at the southeastern margin of the basin (Plate 30). Robinson, an early missionary explorer, visited the area in 1831 prior to European settlement and described the basin as a marshy area lying within a range of stoney hills (Ptomley, 1966).

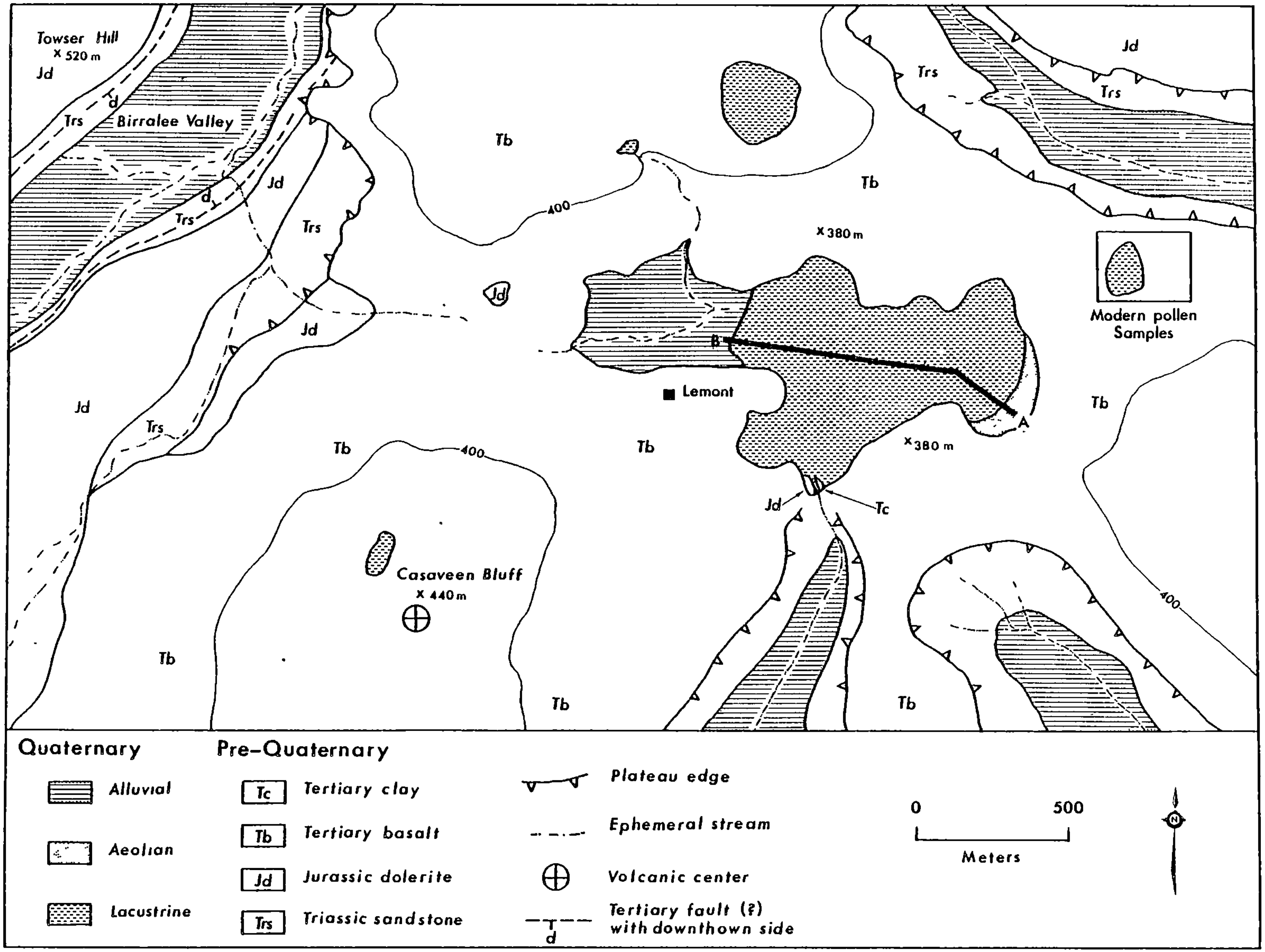


Figure 21. · Location map of lake basin at Crown Lagoon

Plate 29. Lake basin at Crown Lagoon

Plate 30. Lunette at Crown Lagoon

Following settlement the lake floor was used as pasture for cattle and sheep and a network of shallow canals was dug in the late 1880's to facilitate winter drainage. Local residents have stated that the basin is usually dry throughout most of the year, but shallow water does accumulate temporarily following prolonged winter rains.

The only recognizable shoreline is about 1.5 m above the center of the lake floor and it shows no evidence of either recent accretion or erosion. A narrow, fan-shaped alluvial apron, present at the western edge of the basin, is the only defined system of former sedimentation into the lake other than slopewash from the margins. The fan is essentially inactive, and shows no evidence of recent aggradation, except around small areas disturbed by Man or grazing animals. An outlet occurs near the southwestern margin of the basin, but this has been artificially deepened to facilitate drainage.

Pre-Quaternary Geology - As there are no large scale geologic maps of the Midlands, Figure 21 is a reconnaissance survey of the major rock types and structures in the area adjacent to Lemont. The oldest rocks are Triassic sandstones belonging to the Knocklofty Formation. These fine grained, feldspathic sediments only crop out in and around the margins of the Birralee Valley and in a small valley northeast of the lagoon. The sandstones form the valley bottoms and lower slopes, and are easily eroded when stripped of vegetation. Regionally, the Triassic rocks have been intruded by massive sills and discordant sheets of Jurassic dolerite. The dolerite has a very limited surface exposure around the basin, but caps most of the higher tiers in the adjacent area.

Tertiary basalt is the most extensive rock type in the vicinity of the basin. The basalt appears to have been extruded as a single flow from a small vent which forms Casaveen Bluff west of the basin. The flow has been eroded to a low, undulating plain and its surface is part of the uplifted plateau. The vent is degraded to a low cone with concave slopes some 60 m above the level of the plateau.

A thin wedge of clay, apparently of Tertiary age, is exposed for a short distance near the southern outlet drain of the lagoon. These sediments are massively bedded and appear to dip gently to the north. The deposit is composed almost entirely of kaolinitic clay and contains very little or no sand component. A deeply weathered lateritic soil profile, with thin subhorizontal bands of plinthite, is developed on the deposit. The clay is not found elsewhere in or around the basin, and other remnants may have been buried by the overlying lake sediments or removed by erosion.

Surrounded by uplifted dolerite blocks the Birralee Valley is a small graben belonging to the Midlands Graben complex. The faulting probably occurred after the uplift of the erosion surface as there is no evidence of faults in the basalt.

Quaternary Stratigraphy - The lacustrine and aeolian sediments are undissected, and terraces, bars and spits are absent. Because the lake lacks such features of shoreline morphology which might be helpful in determining the sequence of events, this study has emphasized the stratigraphy of the deposits. The stratigraphic relations have been determined from exposures in shallow canals, limited natural sections, and from numerous core and auger holes. Figure 22 is a cross-section of the lake basin reconstructed from the available core and auger determinations. Other interpretations are possible due to the uncertainty in recognizing unconformities and rapid facies changes between core sections. All elevations are relative and are based on an arbitrary datum (Core AB) on the extreme eastern shoreline of the lake floor.

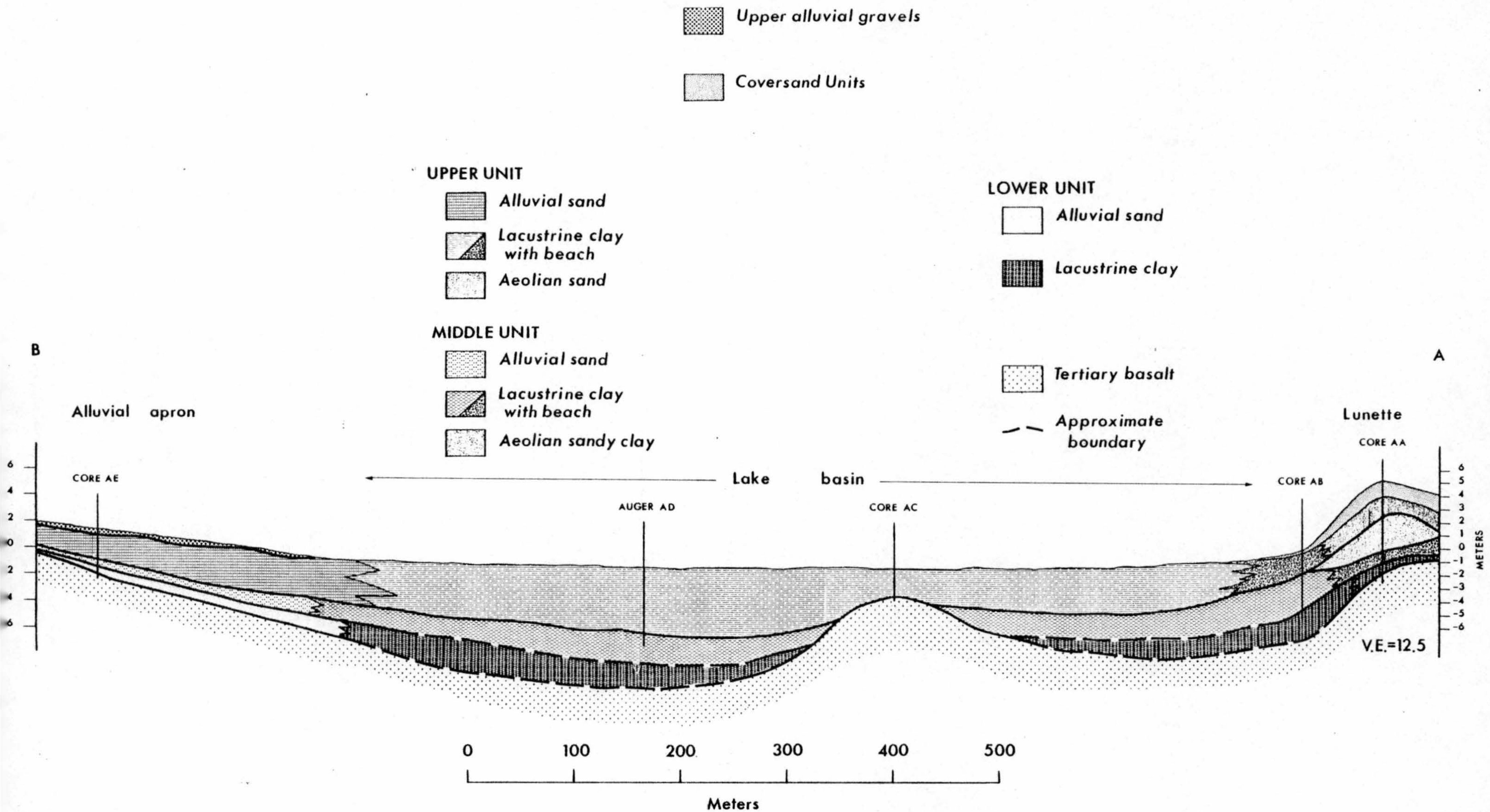


Figure 22. Cross-section of lake basin at Crown Lagoon

The sequence of deposits is differentiated into three major stratigraphic units: *Lower Unit, Middle Unit* and *Upper Unit*. These units were identified on the basis of vertical and lateral variations in gross lithology, texture and color, and not primarily on either the inferred climate during deposition or deduced age differences. The lacustrine sediments have been deposited in a depression formed on the surface of the basalt flow. The subsurface morphology is highly irregular, but the basin may have originally formed as a collapse structure in the flow. Below the basin the basalt is deeply weathered and seismic investigations made for this study indicate a weathering front about 15 m thick (Stephenson, pers. comm.).

The *Lower Unit* contains at least three facies which apparently record the first period of lacustrine sedimentation in the basin. On the eastern side of the lake (Core AA), black carbonaceous clays about 85 cm thick directly overlie the basalt regolith. The clay contains a few rounded, ironstone pebbles and granules, and could be a shallow water deposit which accumulated near the margins of the basin during the high lake stand. Two samples of the material were submitted for radiocarbon dating, but neither contained sufficient organic matter for an age determination.

This deposit appears to grade laterally into grey lacustrine silts exposed in cores some 60 m west of AA. The silt facies is at - 4.20 m and most likely represents a deep water deposit, either directly overlying the basalt or resting on older lacustrine sediments. The silts contain a few rounded, ironstone granules and pebbles. Light grey sands exposed at the base of Core AE on the western side of the basin appear to be a sandy alluvial facies of the Lower Unit; however the lateral extent of this unit is unknown due to poor exposure of the deposit and to limitations on the availability of the drilling equipment.

The stratigraphic relations of the Lower Unit facies are uncertain, but these sediments were probably deposited during a period of high water levels in the lake. The upper boundaries of these sediments are sharp and show no evidence of soil profile development.

The *Middle Unit* contains three known facies which appear to unconformably overlie those of the Lower Unit. These are alluvial sands and gravels; lacustrine clays and beach gravels; and sandy aeolian clays exposed at the base of the lunette. The fan alluvium consists mainly of greyish, pebbly fine to very fine sands about 50 cm thick. The coarse fraction is entirely composed of rounded ironstone pebbles and granules which have been locally concentrated into very thin, subhorizontal lenses. The gravel is weathered and many of the pebbles are almost completely replaced by an insoluble residue of limonite. The sand is mainly well sorted quartz with a few feldspars.

The sands grade laterally into dark brown, silty clays in the center of the basin. The lake clays appear to be massively bedded and are over 3 m thick on either side of the subsurface basalt ridge. These sediments contain a few rounded ironstone pebbles along with a small proportion of medium to fine quartz sand. There is no evidence of chemical precipitates in the lacustrine clays. Between Cores AB and AA, the lake sediments grade eastward into beach gravels about 50 cm thick. The beach is a very poorly sorted, heterogeneous mixture of rounded ironstone pebbles and medium to fine quartz sand. Gravel constitutes about 60 percent of the deposit and most of the pebbles are oxidized giving the beach a red color.

The beach is truncated by a wedge of sandy aeolian clay some 3 m thick at the center of the lunette. The lower part of the aeolian deposit is greyish brown; has a faint pelletal structure;and contains remnants of a few large roots apparently in growth position. The upper 2 m of the dune is brown and also shows an indistinct pelletal structure throughout. The sand fraction is mainly fine quartz sand with feldspar and occasional ironstone grains. Evidence of strong pedogenic alteration was not apparent in the deposit. However, the brown coloration in the upper 2 m could indicate the presence of oxidized iron compounds formed during a phase of subaerial weathering.

The Middle Unit facies seem to form a depositional series related to a second period of high water levels in the basin. The coarser, alluvial material in the fan is mainly pre-weathered regolith locally derived from the Tertiary basalt and/or plinthite, and mixed with large amounts of fine quartz sand. Most of the alluvium is water sorted as indicated by the thin beds of gravel which occur throughout. The lake clays are a deep water equivalent formed by the gradual accumulation of local slope and stream wash material. Wave action, generated by northwest to westerly winds, was primarily responsible for deposition of the beach. The *in situ* modification of the ironstone in the alluvial and beach facies suggests a period of exposure and weathering during a subsequent low water stage.

The sandy aeolian clay in the lunette is most likely derived by the deflation of intermittently exposed, lacustrine sediments by strong northwest to westerly winds. Aeolian activity took place after water levels in the basin dropped, and the weak pelletal structure throughout the dune suggests that sand-sized clay aggregates accumulated by being deflated from the dry lake floor. Lunette deposition of this nature implies environmental conditions favoring frequent, or at least intermittent wetting and drying of the lake floor, possibly with salt efflorescence (Bowler, 1973a; Price, 1963). However, other than the high alkalinity of the Middle Unit lake sediments, there is no direct evidence, such as chemical precipitates, to suggest saline water conditions during the dry lake stage.

The *Upper Unit* deposits appear to unconformably overlie those of the Middle Unit and consist of a nearly similar sequence of alluvial and lacustrine facies. These units intergrade laterally across the basin and record the most recent episode of high water levels and subsequent drying out of the lake. Unlike the older lake deposits, considerably more is known about the Upper Unit facies and their paleoenvironmental significance.

The alluvial material is about 2 m thick, and consists mainly of greyish, weakly consolidated fine sands with ironstone pebbles and granules throughout. Much of the sand is bedded in very thin, subhorizontal lenses, suggesting periodic sedimentation by running water. The alluvium grades laterally to and locally interdigitates with the Upper Unit lacustrine sediments in the center of the basin. The lacustrine sediments consist of fine grained, silty lake clays and a predominantly sandy beach deposited on the eastern side of the basin. The lake sediments are olive grey and consist of massive, non-calcareous clays up to five meters thick on either side of the subsurface basalt ridge.

At Core AC the clays are about 200 cm thick and contain very thin, contorted bands of black organic (?) staining. Small patches of iron oxide and a few root casts replaced by the oxide are present throughout the deposit. In addition, the lower 165 cm of the section contains about 5-10 percent very fine aeolian sand dispersed throughout the deposit. There is a very thin lens of fine sand at - 35 cm in Core AC that consists predominantly of quartz. The lens appears to have only a local distribution as it was not observed in other cores or auger holes dug across the center of the basin. Above the lens, the lake clays appear to contain more organic matter and become very dark brown to black near the surface.

On the eastern margin of the basin, the olive lacustrine clays grade into and interfinger with a predominantly sandy beach facies. At Core AB the beach is about 2 m thick and directly overlies lake sediments deposited during the Middle Unit high lake stage. The beach is composed mainly of well sorted, medium to fine quartz sand with ironstone pebbles and granules throughout. Both the sand and gravel are locally contained in very thin, sub-horizontal lenses, with the gravel making up approximately 15-20 percent of the deposit. The lower half of the beach is greyish brown and grades upwards to brown near the surface.

The beach is a subsurface band of sediment roughly parallel to and just below the old shoreline. The lateral extent of the beach varies considerably and it is widest directly adjacent to the lunette. Sandy sediments are not present along the northern and southern margins of the basin as these areas have rocky shorelines. The orientation of the beach indicates its formation by waves generated by a northwest to westerly wind regime during the last high lake stand.

At Core AB the beach sediments grade into aeolian sands in the lunette without an intervening stratigraphic break. The exact boundary between beach and dune is uncertain since the sediment characteristics of the two deposits are essentially similar near their contact. In addition, the transition between these two facies is likely to be complex given the variety of processes which could act at the interface; including wave action, deflation and slope wash recycling.

The sandy lunette facies has a maximum thickness of about 2 meters and unconformably overlies the sandy aeolian clay of the Middle Unit. At Core AA the lower portion of the deposit is a greyish brown, friable loamy sand which grades upward to a yellowish brown sandy loam at the surface. The sand fraction consists mainly of fine to very fine sand with occasional ironstone granules, especially near the base.

The aeolian sands are thickest near the top and on the lee slope of the lunette and thin rapidly to the east. The orientation of the lunette sands suggest that northwest to westerly winds were responsible for their deposition. A thin, apparently similar sand unit is exposed in the drainage ditch at the southern outlet of the lake. This deposit has a limited distribution and the area has been heavily disturbed from the trench construction. At present the origin of this small unit is uncertain, but it may be a fluvial deposit associated with an overflow stage of the lake.

The textural and soil profile characteristics for the Upper Unit lunette sands are shown in Table 9. In general, the sediments show a strong bimodal distribution of fine sand and clay, and appear to be poorly sorted throughout. Very little silt is present except for a minor peak at 30-35 cm in depth. Clay-sized material is most abundant near the top of the deposit and decreases more or less uniformly with depth. Where derivable, the textural parameters of mean and sorting show little or no variation with depth, other than a weak correlation with the proportion of clay.

The apparent poor sorting of the lunette sands is atypical of most primary aeolian deposits, and in many respects these sediments have textural characteristics similar to those of the principal sandsheets in the lower Derwent Valley. This relationship suggests that the original texture of the lunette sediments have been modified by post-depositional processes, especially weathering. Alternatively, some or all of the lunette sediments could be derived by the deflation of beach and lacustrine material exposed on the lake floor during the last period of low water levels in the basin. However, this conclusion is not fully consistent with the proportion of clay in the deposit

TABLE 9

TEXTURAL AND SOIL PROFILE DATA FOR THE UPPER UNIT LUNETTE SANDS AT CROWN LAGOON[1]

DEPTH CM	SOIL HORIZON	STRUCTURE AND REACTION	COLOR	TEXTURE	SAND %	SILT %	CLAY %	M_z	σ_I	$^E Fe_2O_3$ %	$^T Fe_2O_3$ %	$^T Al_2O_3$ %	$^T Fe_2O_3 + ^T Al_2O_3$ %	CLAY MINERALS			
														MT	I	I/M	K
0-5	B	Very coarse, subangular blocky; weakly acid	10 YR 4/4	Sandy loam	81.45	2.27	16.25	-	-	0.82	3.36	10.95	14.31	xx	x	?	xxx
10-20					79.22	2.20	18.56	-	-	0.87	3.45	11.73	15.18				
30-35					78.85	4.22	16.90	-	-	0.58	3.40	9.89	13.29	xxx	x	-	xx
95-100	C	single grained; weakly alkaline	10 YR 5/2	Loamy sand	86.17	1.43	12.40	3.23	2.46	0.55	3.34	10.24	13.58				
120-130					87.55	2.14	10.31	3.25	2.49	0.30	3.42	9.63	13.05	xxx	x	-	xx

1. S_k and some values of M_z and σ_1 not derivable due to excessive clay in the deposit.

which is greatest in the zone of pedogenic alteration near the top of the deposit. The problem of clay differentiation with regard to mode of origin will be discussed in greater detail in Chapter 10.

Pedogenesis - The Upper Unit beach, aeolian and alluvial sediments are weathered, and each shows a moderate degree of pedogenic alteration, especially oxidation of iron compounds and ped development. The soil unit maintains a similar degree of development across these facies, despite differences in parent material and local drainage conditions. The weathering profile most likely formed during and/or after final drying out of the lake basin. The soil profiles are truncated and the surface horizons are missing.

In the beach and aeolian facies, the upper 30 cm of the B horizon is organized into blocky peds with weak cutans on the interfaces. The beach contains *in situ* weathered ironstone gravel throughout. The lower boundary of the B horizon is gradational and the C horizon is lighter in color and single grained. The pH varies from slightly acid to neutral in the lunette soil profile, but is strongly alkaline in the beach profile due to impeded drainage conditions. There is no evidence of free carbonates in either profile.

The upper portion of the alluvial facies is probably a truncated B horizon as it appears to contain more clay than does the underlying sands. This horizon is organized into blocky peds showing weak cutan development. The ironstone gravel is oxidized, further indicating *in situ* weathering of the deposit.

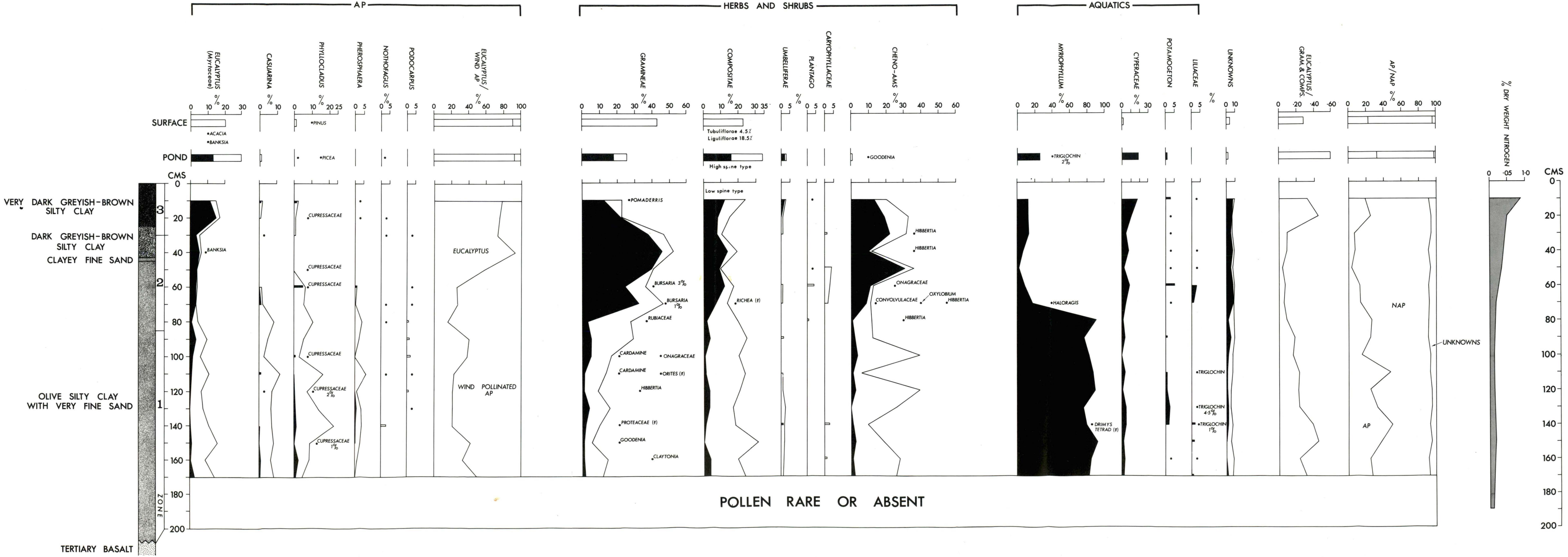
The geochemical and clay mineral data for the lunette deposit show some variation with depth. Extractable iron is highest in the B horizon, and corresponds with the zone of greatest pedogenic development in the soil profile. However, total iron and aluminum show little variation with profile depth, other than being slightly higher in the B horizon. The clay mineral sequence suggests hydrolysis of feldspar and mafic minerals with the partial release of iron in the B horizon, probably in a relatively acid, leaching environment. The abundance of kaolinite in this horizon is similar to that observed in the B horizons of the Bridgewater and Old Beach profiles, and suggests weathering under nearly equivalent conditions.

The soil profile on the lunette and other Upper Unit facies at Crown Lagoon probably formed over a period of several thousand years. The textural, geochemical and clay mineral distributions show a strong resemblance to those determined from the principal sandsheets in the lower Derwent Valley. In as much as these deposits have been shown to be broadly contemporaneous, it is quite likely that the Upper Unit facies at Crown Lagoon were weathered during the same general period of stability, at and since the end of the Last Glacial Stage.

II. POLLEN ANALYSIS

Introduction - Figure 23 presents the relative frequencies of the major pollen types recovered from the modern surface samples and the 2 m core in the Upper Unit lake sediments. Of the thirty-four pollen species identified, the principal arboreal types (AP) included *Eucalyptus*, *Phyllocladus*, *Casuarina* and *Pherosphaera*. The major non-arboreal species (NAP) consisted of Gramineae, Compositae, cheno-ams, Cyperaceae and *Myriophyllum*. These types were present in nearly all samples and accounted for more than 90% of the pollen recovered.

The ratio of *Eucalyptus*/ Gramineae + Compositae was used to approximate the relative importance of eucalypt species in relation to the local herbaceous ground cover. Relatively high values are thought to indicate a forest community while low values are probably more indicative of open savannah or grassland. *Eucalyptus* was also plotted against wind-pollinated arboreal



AP
HERBS AND SHRUBS
AQUATICS
EUCALYPTUS (Myrtaceae)
CASUARINA
PHYLLOCLADUS
PHEROSPHAERA
NOTHOFAGUS
PODOCARPUS
EUCALYPTUS / WIND AP
GRAMINEAE
COMPOSITAE
UMBELLIFERAE
PLANTAGO
CARYOPHYLLACEAE
CHENO-AMS
MYRIOPHYLLUM
CYPERACEAE
POTAMOGETON
LILIACEAE
UNKNOWNS
EUCALYPTUS / GRAM. & COMPS.
AP/NAP
% DRY WEIGHT NITROGEN
%
SURFACE
POND
CMS
ACACIA
BANKSIA
PINUS
PICEA
Tubuliflorae 4.5%
Liguliflorae 18.5%
High spine type
Low spine type
GOODENIA
TRIGLOCHIN 2%
VERY DARK GREYISH-BROWN SILTY CLAY
DARK GREYISH-BROWN SILTY CLAY
CLAYEY FINE SAND
OLIVE SILTY CLAY WITH VERY FINE SAND
TERTIARY BASALT
ZONE
3
2
1
CUPRESSACEAE
CUPRESSACEAE 2%
CUPRESSACEAE 1%
EUCALYPTUS
WIND POLLINATED AP
POMADERRIS
BURSARIA 3%
BURSARIA 1%
RUBIACEAE
CARDAMINE
ONAGRACEAE
ORITES (?)
HIBBERTIA
PROTEACEAE (?)
GOODENIA
CLAYTONIA
RICHEA (?)
ONAGRACEAE
CONVOLVULACEAE
OXYLOBIUM
HALORAGIS
DRIMYS TETRAD (?)
TRIGLOCHIN
TRIGLOCHIN 4.5%
TRIGLOCHIN 1%
NAP
AP
UNKNOWNS
POLLEN RARE OR ABSENT

Figure 23. Pollen diagram from Crown Lagoon

pollen to demonstrate the relative importance of other species in the samples. The percent dry weight nitrogen was included in the pollen diagram to evaluate the relationship between trophic levels and changes in the pollen frequencies. Plate 31 shows the structure of the modern vegetation community and Table 10 provides a list of the major species in the vicinity of the modern sampling sites with an estimate of their relative cover (Kirkpatrick, pers. comm.).

In the surface soil samples a single 200-grain pollen sum was counted, and the assemblage was dominated by *Eucalyptus* (20%), Gramineae (46.5%) and Compositae (23%). In relation to the relative cover of the species, the abundance of eucalypt pollen suggests that either the local trees are prodigious pollen producers or that some component of wind-transported *Eucalyptus* pollen is included in the total. *Eycalyptus* is generally considered to be insect pollinated (Pryor and Boden, 1962), although birds could also be an important vector in pollen dispersal (Jackson, pers. comm.). However, there is abundant evidence to indicate that eucalypt pollen is mainly dispersed by wind (Churchhill, 1968; Speck, 1953). The most important source of wind transported eucalypt pollen in this area is the dense forests on the adjacent tiers.

Other AP included *Casuarina* (0.5%), *Banksia* (0.5%) and *Acacia* (0.5%). The low frequency of these may result from a limited plant distribution, low pollen productivity and/or dispersal of some species, and possibly the constraining effect of the relatively high NAP in the sample. *Phyllocladus* (1%) is the only long distance, indigenous AP species in the sample. The nearest source for this pollen is about 40 km west of the site on the Central Plateau (Jackson, 1974). Other AP included low percentages of *Pinus* and Cupressaceae, probably derived from introduced species.

The dominance of Gramineae and Compositae in the NAP reflects the abundance of these families around the site. Gramineae taxa vary considerably

Plate 31. Eucalypt savannah and site of modern pollen samples near Crown Lagoon

TABLE 10

MAJOR PLANT SPECIES AT THE MODERN POLLEN SAMPLING LOCATIONS NEAR CROWN LAGOON

SAVANNAH		MARSH	
Species	Relative Cover (%)	Species	Relative Cover (%)
Eucalyptus pauciflora	<5	*Myriophyllum* spp.	40
E. ovata	<5	*Pratia* spp.	5
Banksia marginata	rare	*Villarsia exaltata*	30
Coprosma quadrifida	rare	*Eleocharis* spp.	5
Poa spp.	45	*Hydrocotyle* spp.	<5
Danthonia spp.	20	Gramineae	<5
Themeda australis	10	*Triglochin procera*	<5
Convolvulus spp.	5	*Utricularia* spp.	<3
Cyperaceae	3	*Lepidosperma* spp.	<1
+ *Rumex angiocarpus*	rare	*Juncus* spp.	<1
+ *Plantago major*	2		
Oxalis corniculata	<1		
Acaena ovina	<1		
Geranium spp.	rare		
+ *Anagallis arvensis*	rare		

+ Introduced species

in pollen production (Jones and Newell, 1948), but the high percentages suggest local over-representation and/or the low pollen productivity and dispersal of other species. Compositae included 18.5% Liguliflorae and 4.5% Tubuliflorae, all of which were low-spine types. Unfortunately,the composites could not be further subdivided into endemic and introduced species. Other NAP included low percentages of Cyperaceae (3%), Umbelliferae (0.5%) and *Dodonaea.*

The marsh sample was collected from the surface sediment of a small depression adjacent to the location of the soil sample. Drainage into the depression is restricted to surface wash from the surrounding hillslope and there are several high litter lines around the marsh which suggest that water levels fluctuate periodically.

In the first sum the AP consisted of *Eucalyptus* (13%) and *Picea* (0.5%), and the NAP was dominated by *Myriophyllum* (26%), Cyperaceae (10.5%), Gramineae (18.5%) and Compositae (16%). Other NAP included low percentages of Umbelliferae, *Potamogeton* and *Triglochin*. *Myriophyllum* and Cyperaceae are the major aquatic species, and their combined pollen frequency appears to be under-represented in relation to the other pollen species, especially grasses.

The abundance of Gramineae and Compositae pollen could suggest intermittent plant colonization of the marsh when dry. Alternatively these types could be derived from wash off the adjacent slopes. The composites consist only of high spine, Tubuliflorae types as distinct from the abundance of Liguliflorae in the soil sample.

In the second sum, excluding aquatics, the frequency of *Eucalyptus* rose to 30.5% which indicates that the marsh is acting as a trap to concentrate the non-aquatic pollen. Other AP included low frequencies of *Phyllocladus* (0.5%), *Casuarina* (1.0%), *Nothofagus* (0.5%) and Cupressaceae (0.5%).

Gramineae (26%) and Compositae (34.5%) increased in abundance in the second sum suggesting both local over-representation and the concentrating effect of the marsh. Cheno-ams (1%) may be the product of long distance transport from coastal areas or the pollen could be derived from a local source. There are several native and introduced chenopods in Tasmania. Most of the native species occur in salt marsh communities on the coasts, although *Chenopodium glaucum* has been reported around some inland lakes in the Midlands (Curtis, 1967). *Ptilotus spathulatus* and *Alternanthera denticulata* are native amaranths which occur in dry areas throughout the state and in marshy depressions in the Midlands.

The ratio of *Eucalyptus*/Gramineae + Compositae in the soil surface sample is 0.29 and 0.50 in the marsh, which gives a range of values for the modern eucalypt savannah around Crown Lagoon. The ratio derived from the surface samples may be somewhat unreliable due to the high probability of introduced species in the Compositae pollen value.

Fossil Pollen Record - As there are no detailed pollen studies from the lowlands of Tasmania, the Crown Lagoon sequence cannot be correlated with others. The pollen sequence is derived from a single section (Core AC), and as radiocarbon control is not available, there is no certain means of determining when the record begins or ends. The possible vegetation interpretations and paleoclimatic inferences derived from the pollen must be considered with these limitations in mind. The Upper Unit lacustrine sediments are divided into three zones based on broad changes in the relative pollen frequencies.

In the initial sum the *Zone 1* assemblage is completely dominated by *Myriophyllum* (76.5 - 92.5%) with all other types occuring in low percentages. The AP consisted mainly of *Eucalyptus*, *Casuarina*, *Phyllocladus* and *Pherosphaera*.

The major NAP species include Gramineae, low-spine Compositae and cheno-ams. Other aquatic pollen consisted of Cyperaceae, *Potamogeton, Drimys* and *Triglochin.* Spores were frequent to abundant, including several of *Dicksonia antarctica.* Pollen other than *Myriophyllum* was rare or absent below 180 cm.

The adjusted sum revealed varying amounts of arboreal pollen (15-48%) including relatively high percentages of *Phyllocladus, Casuarina* and *Pherosphaera.* There were also low percentages of other wind-pollinated species including *Podocarpus alpina, Nothofagus cunninghamii* and Cupressaceae. *Eucalyptus* varied between 5 to 16.5%.

The adjusted NAP was dominated by composites, Gramineae and cheno-ams with lesser amounts of Umbelliferae and Caryophyllaceae. Gramineae was present in lower percentages than in the modern samples, but increased in abundance near the top of the zone. The composites consisted exclusively of wind-pollinated low spine types and were generally evenly distributed, except for a marked rise at 150 cm. Cheno-ams were present in variable amounts and showed two marked peaks at 100 and 120 cm. Other NAP in the second sum included low percentages of *Claytonia, Goodenia,* Proteaceae (?), *Hibbertia* and Rubiaceae.

The relatively low nitrogen values throughout Zone 1 suggest low accumulation and/or preservation of organic matter during most of the period of deposition. Nitrogen values are not available from other parts of the basin, but the uniform grey coloration and visible absence of organic matter in most of the Upper Unit lake sediments suggest that oligotrophic conditions prevailed during deposition.

The *Zone 2* assemblage was marked by a sudden decline in the relative abundance of *Myriophyllum* and a rise in Cyperaceae pollen in the first sum. In the adjusted sum there was a marked rise in the abundance of Gramineae and a reduction in the frequency of Compositae. The AP included low percentages of *Eucalyptus*, *Phyllocladus* and *Casuarina* with small amounts of *Pherosphaera* and other rainforest species. Wind pollinated AP did not occur above 50 cm and the relative abundance of *Eucalyptus* was very low.

Cheno-ams were present in varying amounts and showed a marked increase at 50 cm. Umbelliferae, *Plantago* and Caryophyllaceae pollen occurred throughout, with the highest percentages between 50 to 70 cm. Other NAP included Convolvulaceae, *Haloragis*, *Richea* (?) and *Bursaria spinosa*. Spores were common throughout, but were less frequent than in Zone 1. The pollen was not as well preserved as in Zone 1, and finely divided charcoal occurred in all levels above 50 cm.

The sharp decrease in *Myriophyllum* may indicate a hiatus between Zones 1 and 2, but there are no apparent unconformities near the base of Zone 2. The only marked change in sedimentation within the core is the thin and discontinuous sand lens which lies in the upper part of Zone 2. The major pollen changes that occur at this level are the disappearance of *Phyllocladus*, a small increase in Compositae, and a sharp reduction in cheno-ams. The possibility exists that both periods of erosion and of relative stability are present in Zone 2 and some of the pollen fluctuations may be due to the effects of redeposition.

The *Zone 3* assemblage was characterized by a marked increase in the abundance of *Eucalyptus* with the reappearance of *Phyllocladus* and *Casuarina* in low percentages. The rise in AP was apparent in both sums, and corresponded with a reduction in Gramineae and an increase in low spine composites. Cheno-ams also decreased in abundance towards the top of the zone. *Myriophyllum* increased to about 14% and remained relatively constant. This corresponded with a gradual increase in the abundance of Cyperaceae and other aquatic pollen towards the top of the zone. Other NAP included low percentages of Umbelliferae, *Plantago*, and *Hibbertia*.

Spores were considerably less abundant than in Zone 2, but finely divided charcoal occurred throughout the samples. Pollen preservation was generally poor and many of the grains were corroded by oxidation. The relative increase in nitrogen and darker color of the Zone 2 and 3 sediments implies much greater productivity of aquatic plants and microflora during and at the end of these depositional phases.

III. COVERSAND UNITS ON THE LUNETTE

The Upper Unit lunette and beach deposits are irregularly truncated and are unconformably overlain by a series of secondary aeolian units similar to those at Glenfield and Old Beach in the lower Derwent Valley. These sediments are best exposed in a linear deflation hollow near the top of the lunette and consist of three, superimposed fine sand units (Fig. 24; Plate 32).

Stratigraphy - The coversands of *Unit 1* directly overlie the truncated B horizons formed on the Upper Unit aeolian and beach sediments (Plate 33). This deposit is a massively bedded, wedge of loosely consolidated fine sand up to 130 cm thick. The unit is thickest near the top and on the lee slope of the lunette, and thins rapidly to the east and west. The sands are continuous from the lunette to the lake shore where the deposit overlies the beach sediments. Here, the unit rests on a lag layer of pebbles and granules consisting of weathered ironstone derived from the beach. There is little or no mixing of the sand with the lag gravels, and Unit 1 does not grade into, nor does it overlap onto the Upper Unit lake clays. Unit 1 appears to have been deposited by northwest to westerly winds and its limited distribution indicates a local deflation source.

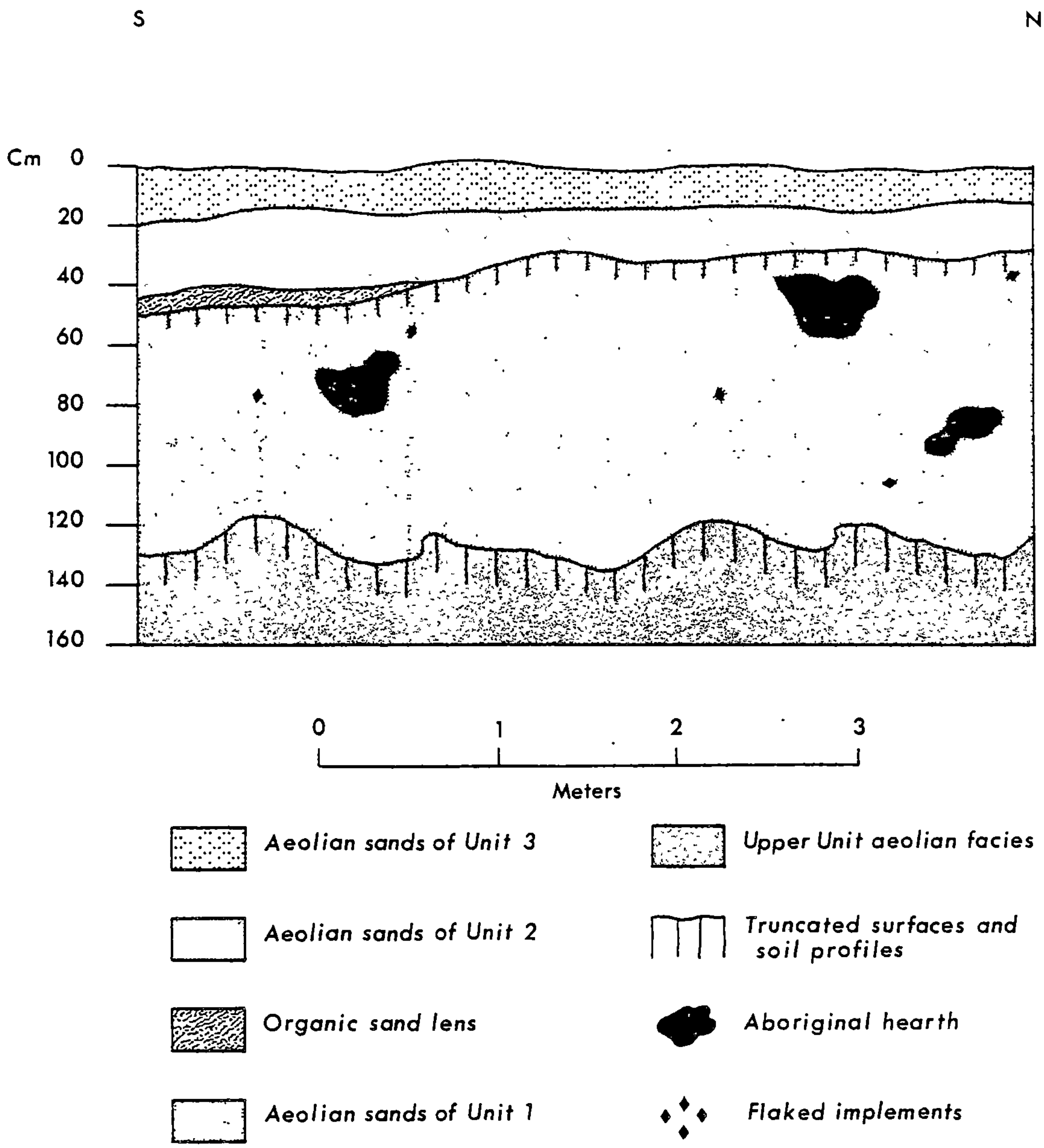


Figure 24. Aeolian stratigraphy of the coversand units on the lunette at Crown Lagoon

Plate 32. Coversand units on lunette at Crown Lagoon. Note Aboriginal hearth near base of Unit 1.

Plate 33. Coversand units overlying truncated surface of Upper Unit lunette sands at Crown Lagoon

As shown in Table 11, the sands are well sorted, nearly symmetrically skewed, and have a mean grain size distribution of about 2.3 Ø. The modal diameter of the sand is between 2.5 to 3.0 Ø, and the difference between this value and the mean is due to the inclusion of medium sand-sized, ironstone grains in the deposit. The sand fraction consists mainly of quartz with lesser amounts of feldspars, dark mafic grains and ironstone. Very little silt or clay is present in the deposit.

The upper 15-20 cm of the unit is brown to locally yellowish-brown and grades to pale brown near the base. The redder hue in the upper portion of the deposit indicates that aeolian deposition was followed by local stability and weathering. Weathering appears to have been only oxidation of iron compounds as there is little or no textural differentiation in the profile.

The surface of Unit 1 is sharply truncated and is locally overlain by a thin and discontinuous lens of very dark brown, fine sand 0-10 cm thick (Plate 36). The dark hue is due to finely divided charcoal and dispersed organic matter. The lens provides clear evidence of the separate stratigraphic origin for the coversand sequence on the lunette.

Unit 1 and the thin lens of organic sand are unconformably overlain by the aeolian fine sand bed of *Unit 2* which is 15-30 cm thick. The unit consists of loosely consolidated, well sorted fine quartz sand which is dark brown and contains finely divided charcoal. The bed thins towards the basin, and is thickest near the top and on the leeward slope of the lunette. These sediments unconformably overly Unit 1 near the margins of the lunette, but here the thin lens of organic sand that separates the two units is missing. Unit 2 is always found in association with Unit 1 and was not observed in contact with the truncated surface of the Upper Unit lunette sands.

TABLE 11

TEXTURAL DATA FOR THE COVERSAND UNITS ON THE LUNETTE

AT CROWN LAGOON

DEPTH CM	UNIT	STRUCTURE AND REACTION	COLOR	TEXTURE	SAND	SILT + CLAY	M_z	σ_I	S_k
15-20	3	Single grained weakly acid	10 YR 5/4	sand	98.47	1.53	2.25	0.57	0.20
27-33	2	Single grained weakly acid	7.5 YR 3/2	sand	98.84	1.16	2.32	0.54	0.13
35-40					98.69	1.31	2.35	0.55	0.13
55-60	1	Single grained weakly acid	7.5 YR 5/3	sand	99.21	0.79	2.35	0.53	0.08
75-80					98.33	1.67	2.37	0.55	0.15
95-100					98.03	1.07	2.26	0.55	0.17
125-130			10 YR 6/3		99.30	0.70	2.24	0.55	0.10

The surface of Unit 2 is truncated and is unconformably overlain by an aeolian fine sand 10-30 cm thick which forms *Unit 3*. This unit is continuously distributed on the lunette and locally overlies the surface of the older Upper Unit lunette sands. Unit 3 is yellowish brown and consists of well sorted quartz. The deposit does not occur near the lake shore and increases in thickness on the lee slope of the lunette. There is no evidence of soil profile development on either of the upper two units.

The textural characteristics of Units 2 and 3 are very similar to those of Unit 1. All are composed of well sorted, fine sand with a nearly symmetrical grain size distribution, and in this respect, each unit is similar to most other modern aeolian deposits of the same caliber. Each unit was deposited by northwest to westerly winds, and the relatively narrow mean and modal ranges for the sediments indicates a strong genetic relationship between the units. These similarities and the local stratigraphic relations indicate that the coversand units are derived from successive periods of human activity and groundsurface disturbance on the lunette.

The coversand units do not occur on the alluvial apron leading to the lake, nor are they present in the lake sediments or on the adjacent drainage divide. The truncated surface of the Upper Unit alluvium is sharply truncated and overlain by about 25 cm of pebbly ironstone gravel in a light grey, silty matrix. These gravels thin towards the lake basin, and do not overlie the lacustrine sediments of the Upper Unit.

These gravels are fresh and unweathered, and appear to occupy the same relative stratigraphic position as do the Unit 1 coversands on the lunette. The gravels most likely represent the accumulation of locally derived material eroded from the lake catchment during one or several periods of instability resulting from the activities of Man, especially in the time since European occupation of the area.

<u>Archeology and Dating</u> - Unit 1 contains abundant evidence for Aboriginal occupation during the Holocene (Lourandos, 1970). Several hearths and implements are exposed in the deflation hollow, and where modern wind erosion has eroded the unit, numerous implements litter the surface of the Upper Unit lunette sands (Plates 34 and 35). Lourandos conducted extensive excavations in Unit 1, and obtained two radiocarbon dates from hearths of 4,170 ± 80 BP (ANU-279) and 4,860 ± 95 BP (ANU-278); however the stratigraphic position of the hearths was not precisely identified.

Lourandos suggested that the dates bracket the densest part of the cultural occupation found in the upper part of the unit. The base of the sands apparently contained little archeological material, and he interpreted this as due to either differential Aboriginal activity at the site or some change in the rate of aeolian deposition.

The excavations revealed a great variety and abundance of stone implements, and from this evidence Lourandos concluded that the site was a temporary hunting camp organized for the exploitation of local game resources. This conclusion was partially based on the high density of flaked and retouched artifacts in relation to the small number of grinding tools present in the assemblage. Poorly preserved bone was present throughout the deposit, and one fragment was identified as the Forester kangaroo (*Macropus giganteus tasmaniensis*).

From the presence of numerous hearths and flaking floors in the unit, Lourandos suggested that there were several different areas of cultural activity at the site during the period of occupation. He further indicated that Aboriginal occupation coincided with a mid-Holocene arid phase during which the sands were deflated from a seasonally dry lake floor, but he did not speculate or mention a specific source of the sand.

Plate 34. Large Aboriginal hearth area associated with Unit 1 on lunette at Crown Lagoon (Photo by A. Goede)

Plate 35. Aboriginal implements exposed on surface of Upper Unit lunette sands at Crown Lagoon (Photo by A. Goede)

The thin lens of aeolian sand which separates Units 1 and 2 also contains large fragments of charcoal and small flakes of lithic material (Plate 36). This association was not noted in Lourandos' archeological evaluation of the site, and the lens is a local surface of Aboriginal occupation that followed the deposition and minimum oxidation of the Unit 1 sands. Units 2 and 3 do not contain evidence of Aboriginal occupation and these units probably accumulated after abandonment of the site. This conclusion is supported by the presence of rabbit bones, iron nails and shotgun pellets in Unit 4.

Plate 36. Thin, organic sand lens separating Units 1 and 2 on lunette at Crown Lagoon

CHAPTER 9

WHITE LAGOON

Numerous lagoons and small salt pans occur throughout the central portion of the Midlands; the largest is Grimes Lagoon near Mona Vale (Fig. 4). All the basins are relatively shallow features which generally occur on flat interfluves of the Macquarie River and its major tributaries. Most of the depressions contain water in winter, but dry out in summer leaving a thin coating of salt on the exposed floors. The origin of the salt is unknown, but Nye (1921) suggested that it was derived from thin saline lenses which occur locally near the base of the Triassic sediments.

This brief chapter presents geomorphic and stratigraphic evidence from a second lunette at White Lagoon in the Midlands. This information is mainly derived from a road-cutting through the lunette. Unfortunately, coring equipment was not available to provide subsurface data on the adjacent lake sediments. However, the site does provide correlative information on the late Quaternary environment in this region and supplies additional data to support future research on lunette formation in Tasmania.

Geomorphic and Stratigraphic Relations - White Lagoon is a very small lake located 4 km north of Tunbridge on the Midlands Highway (Fig. 25). The area is some 12 km east of the Central Highlands escarpment and lies west of the broad, northward flowing Macquarie River. The basin receives its drainage from a small ephemeral stream which occupies a narrow valley leading to the Blacksmans

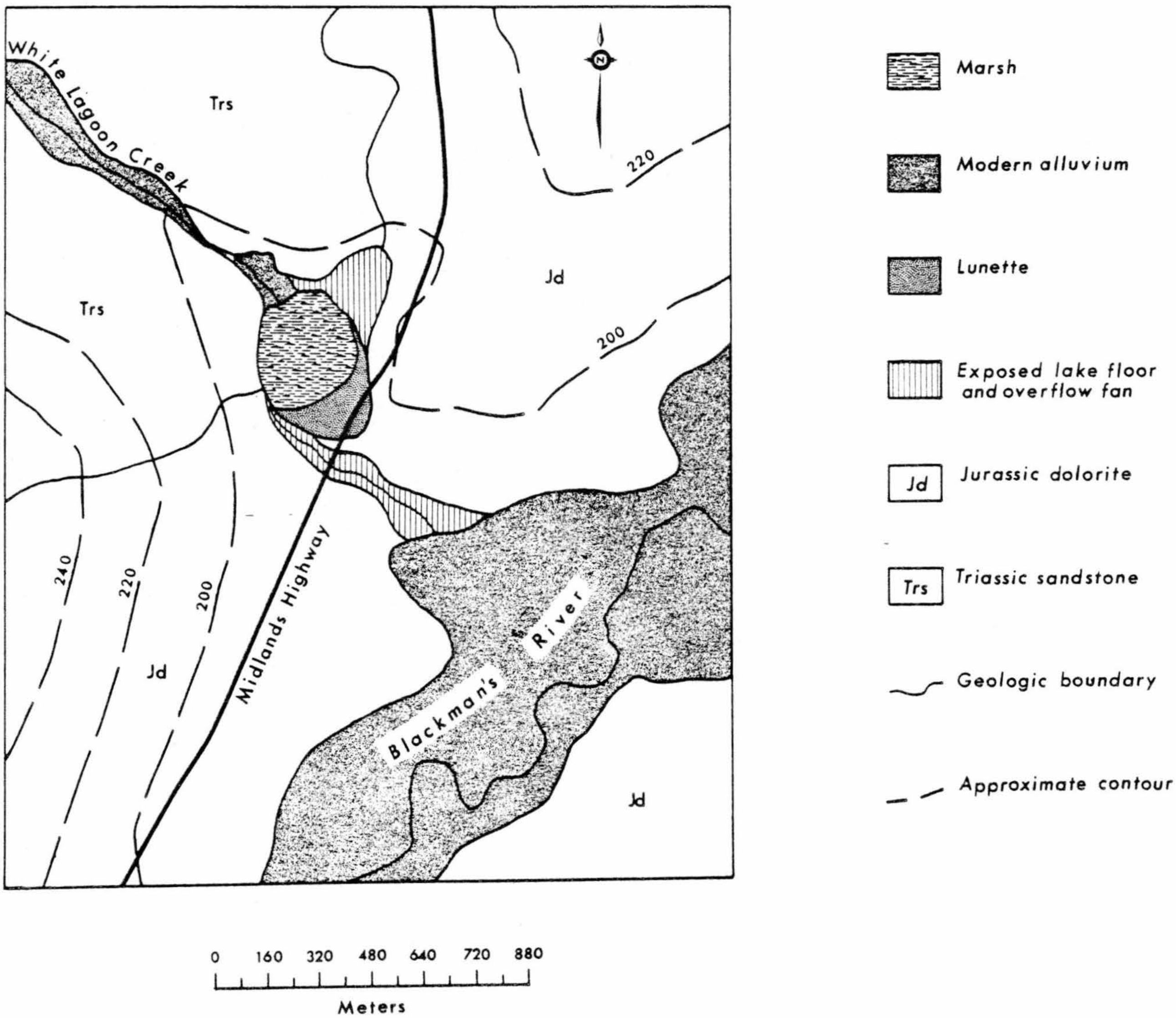


Figure 25. Location map of lake basin at White Lagoon

River, a tributary of the Macquarie. The lagoon covers about 10 hectares, and it is an elliptically shaped depression filled with about 1 m of fresh water (Plate 37). The basin was formerly drained by a small outlet fan to the south, but this feature is now artifically blocked to maintain high water levels throughout the year. The low-lying lunette, about 4 m above present water level, occurs at the southeastern margin of the basin (Plate 38).

The only pre-Quaternary rocks which crop out near the basin are Triassic sandstones and Jurassic dolerite. The dolerite forms prominent cliffs north and west of the lagoon, while the more easily eroded sandstones are found in the valley bottom and gentle lower slopes.

The lunette, lake basin and surrounding alluvial valley are undissected and natural exposures are absent. Augering was not attempted due to the high water level in the lake and heavy clay sediments which form the lunette. However, a cross-section of the lunette is exposed in a road-cut some 80 m southeast of the basin. The sediments here consist of four main stratigraphic units: a basal gravel overlain by three superimposed aeolian deposits which compose the body of the lunette (Fig. 26).

The lowest deposit (Unit 1) is a thin bed of fluvial gravels about 30 cm thick which rests directly on weathered dolerite. The gravels are massively bedded and contain rounded dolerite pebbles and cobbles in a red, fine quartz sand to silt-clay matrix. The unit is exposed only at the southern end of the lunette and for a short distance beyond the dune, where thin remnants of gravel locally mantle the valley slope. The gravels do not grade into the modern alluvium in the Blacksmans Valley, but appear to have been deposited at a much higher level.

Plate 37. Lake basin at White Lagoon

Plate 38. Lunette at White Lagoon

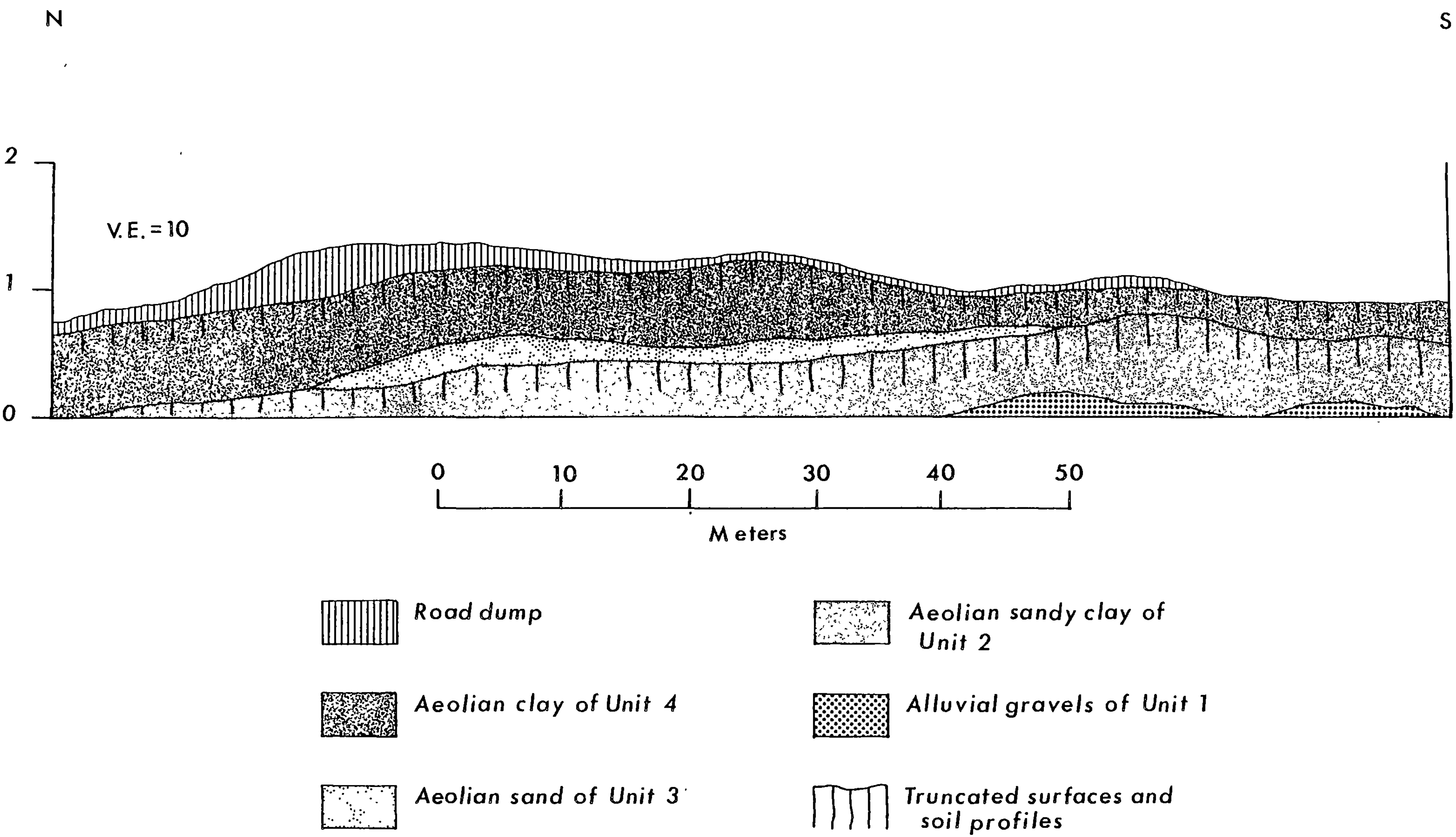


Figure 26. Cross-section of the lunette at White Lagoon

The alluvial gravels are overlain by a massively bedded, aeolian sandy clay of Unit 2 which forms the broad base of the lunette. This deposit is exposed for about 160 m in the cutting and reaches a maximum thickness of some 120 cm near the center of the dune. The sediments preserve a very weak pelletal structure throughout suggesting the presence of clay aggregates. Very coarse grains and granules of rounded ironstone are locally abundant in the deposit, especially near the southern limits of its exposure.

The textural and soil profile characteristics for Unit 2 are presented in Table 12. Textural parameters of mean, sorting and skewness cannot be derived due to the significant proportion of clay in the deposit, but the sediments are undoubtedly poorly sorted and fine skewed. Clay is most abundant in the upper portion of the deposit and this fraction decreases with depth. The silt content is relatively low and uniformly distributed throughout the deposit. The sand fraction appears to be well sorted with a modal diameter of about 3. 0 Ø, and consists predominantly of quartz with subordinate amounts of feldspar and dark mafic mineral grains. By comparison, the grain-size characteristics of this deposit are significantly different than those of the lower Derwent sandsheets (see Chapter 4) and the Upper Unit lunette sands at Crown Lagoon, especially in the amount and distribution of clay-sized material.

The sandy clay is confined to the lunette ridge and does not overlie remnants of the alluvial gravels exposed southeast of the dune. The deposit forms the central core of the lunette and the sedments were deflated from the basin by winds which came from the northwest. The presence of ironstone grains and granules in the unit suggests high

TABLE 12

TEXTURAL AND SOIL PROFILE DATA FOR UNIT 2 AT WHITE LAGOON[1]

DEPTH CM	SOIL HORIZON	STRUCTURE AND REACTION	COLOR	TEXTURE	SAND	SILT	CLAY
10-15	B	Fine to medium well developed subangular blocky; alkaline	5 YR 4/5	Sandy Clay	56.03	4.44	41.42
35-40					59.95	4.45	35.59
60-65	C	single grained to granular weakly acid to alkaline	7.5 YR 5/6	Clayey Sand	65.36	4.59	30.03
90-95					71.58	3.84	22.26
125-130					73.18	4.06	22.75

1. M_z, σ_I and S_k not derivable due to excessive clay in the deposit.

intensity winds during deposition and some of this material may have been eroded from a beach. However, the high proportion of clay in the deposit indicates that the unit is a clay dune variation derived primarily from the deflation of fine-grained lacustrine sediments exposed on a drying lake floor. This conclusion is further supported by the indistinct pelletal structure of the deposit which suggests the presence of wind-blown clay aggregates.

The surface of Unit 2 is truncated and the deposit is unconformably overlain by a thin bed of sand which forms Unit 3. This lens, up to 30 cm thick, is only exposed in the central part of the cutting and appears to dip sharply toward the lake basin. The deposit is massively bedded and consists predominantly of well sorted, medium to fine quartz and feldspathic sand with very little silt or clay matrix.

The sand fraction of Unit 3 is considerably coarser than is that which composes the underlying sandy clay, and on this basis, the two units are clearly different sedimentary units. The absence of any appreciable silt or clay fraction in the lens indicates a predominantly sandy deflation source in the lake basin, and the sands are most likely derived from the deflation of beach sediments during a subsequent high water stage in the basin.

In support of this conclusion, the sands of Unit 3 are texturally similar to the weakly bedded, medium to fine sands which compose the outlet fan south of the basin. The fan leads to the Blackmans Valley and truncates the older remnants of the Unit 1 alluvial gravels. The toe of the fan is buried by the modern floodplain sediments in the valley and the fan most likely accumulated during successive phases of lake overflow. To the north the alluvial sands grade laterally into sandy lacustrine clays exposed around the elliptical depression cut into the center of the basin. These sediments are weakly bedded and lie about 1 m above the floor of the depression. They apparently represent sedimentation over the final high lake stage in the basin prior to the construction of the artificial dam. The facies and textural similarities of the aeolian sand lens, the outlet fan and the exposed lake sediments indicate a close relationship between these deposits, and all phases of sedimentation probably occurred during the last major high lake stage.

The surface of the sand lens is sharply truncated and the deposit is overlain by a wedge of aeolian clay (Unit 4) between 20 to 120 cm thick. This unit is the uppermost deposit in the lunette and increases in thickness toward the northern end of the cutting. The clay is massively bedded and preserves a very distinct granular structure. Small amounts of fine to medium quartz sand are present throughout in the deposit, and there are a few weakly defined, subhorizontal lenses near the base. Small nodules of carbonate occur throughout the dune, but these are relatively more abundant in the lower half of the deposit.

Unit 4 forms most of the surface morphology of the dune. The edge of the deposit is locally modified by modern wave action, but the windward slope is much steeper than the lee slope; a feature characteristic of most clay dunes (Bowler, 1973a). The "horns" of Unit 4 overlie the lacustrine clays to the north and the sediments of the outlet fan to the south. This relationship clearly indicates that the deposition of the clay post-dates the last major phase of lacustrine sedimentation in the basin.

Unit 4 was derived from the deflation of lake sediments exposed on a drying lake floor, and the form and orientation of the dune indicates a predominantly northwesterly wind direction during deflation. Also, the distinct granular fabric of the clay suggests the deflation of sand-sized clay aggregates produced on the exposed lake floor. The wind erosion of lacustrine sediments formed the depression in the center of the basin. The remaining exposed lake sediments are covered with a thin, broken pavement of carbonate nodules, some of which are thinly laminated. The carbonate indicates that alkaline conditions were established with possible saturation of the lake waters prior to and/or during the final phase of desiccation and deposition of the aeolian clays.

Pedogenesis - Several of the deposits exposed in the lunette have been weathered and show distinct soil profiles. The basal alluvial gravels are strongly altered and show weathering rinds up to 10 mm thick. Most of the cobbles are coated with a thin film of red cutanic material consisting of clay minerals and iron oxides. This evidence indicates that alluvial deposition was followed by a period of stability and weathering. The intensity or duration of weathering cannot be determined, but the extent of rind development suggests a prolonged period of exposure under oxidizing conditions.

Unit 2 has been weathered following its deposition and shows relatively strong profile development (Plate 39). The profile is truncated, and the A and probably part of the B horizon are missing. The upper part of the profile, interpreted as the B horizon, shows well developed, blocky peds coated with continuous cutans. The ped faces and cutanic material are locally coated with a thin film of weakly adhesive free carbonate

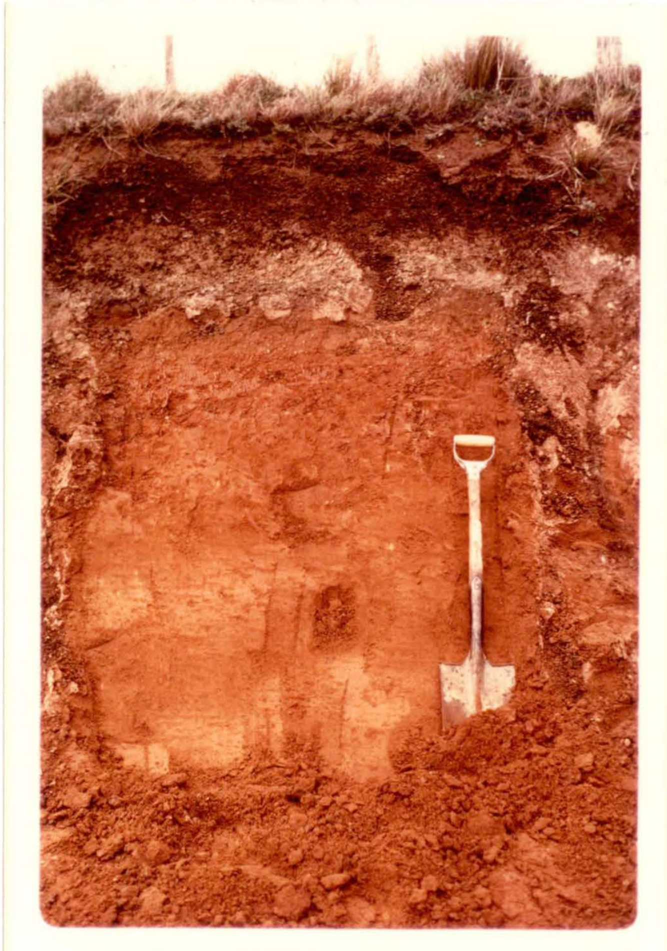


Plate 39. Truncated soil profile on Unit 2 at White Lagoon. Note free carbonate concentrated above paleosol.

probably derived from the overlying aeolian clay. Carbonate is also present as small nodules and tubules around roots, and is more abundant near the truncated surface of the B horizon than at depth. The lower boundary of the B is gradational and the C horizon has single grained structure. Carbonate is rare in the C, and where present, the ironstone granules show little or no evidence of *in situ* pedogenic alteration.

Unit 3 shows little or no evidence of soil profile development. The sand lens is uniformly brown in color and has a single grained structure throughout. The virtual absence of soil profile in this deposit suggests that only a short interval of stability occurred prior to burial by the aeolian clays of Unit 4.

Unit 4 is weathered and shows evidence of a distinct soil profile. The A horizon of the profile is very dark brown and has a very fine, subangular blocky to locally granular structure. The peds, where present, are coated with a continuous network of stress cutans. The lower boundary of the A is gradational and passes directly into an olive grey C horizon. The structure of this horizon is granular with minimum development of very fine, blocky peds. Free carbonate occurs throughout the C horizon as either thin discontinuous vertical sheets or small nodules and tubules. The carbonate is most abundant near the base of the profile and is locally continuous into the upper portion of the Unit 2 paleosol. The soil developed in Unit 4 resembles a chernozem-type profile and is probably forming at the present time in the marginally semiarid environment which characterizes this portion of the Midlands.

The aeolian deposits exposed at White Lagoon provide a contrasting sequence to those from Crown Lagoon. Both lunettes contain evidence for multiple periods of aeolian activity and subsequent weathering. The following chapter attempts to interpret and correlate the sequences which occur at Crown Lagoon and White Lagoon.

CHAPTER 10

INTERPRETATION AND CORRELATION OF THE MIDLANDS SITES

Crown Lagoon and White Lagoon are small, but complex hydrologic systems whose histories reflect a number of past environmental changes. Both lakes drain relatively small catchments and are essentially closed basins. Given their small sizes, each would tend to be more sensitive to local environmental changes than would a significantly larger lake basin. However, the major hydrologic changes and associated phases of aeolian activity recorded from both sites are related to changes in climate during the Pleistocene.

Correlations between the two sites are uncertain as the sedimentary sequences are not strictly similar; each contains a variety of deposits derived from a variety of geomorphic processes. Absolute time control is not available for the major periods of deposition, and correlations between these, and other sites are tentative. Since data are more readily available from Crown Lagoon, this evidence will be first used to establish a tentative relative sequence of events with which White Lagoon will then be compared.

I. CROWN LAGOON

The history of Crown Lagoon is related to a complex interaction of alluvial, lacustrine and aeolian processes. Table 13 presents a generalized sequence inferred from the known stratigraphic record, and where,possible a tentative climatic reconstruction is suggested for each major stage.

Lower Unit Sequence - The Lower Unit facies provide the oldest known evidence of lacustrine sedimentation in the basin. These sediments, consisting of alluvial sands and both deep water and near shore clays, were deposited after deep weathering in the underlying basalt had occurred.

TABLE 13

PROVISIONAL LATE QUATERNARY SEQUENCE FROM CROWN LAGOON

STRATIGRAPHIC UNIT		FACIES				LAKE STAGE	POLLEN	VEGETATION	CLIMATIC RECONSTRUCTION	GEOLOGIC AGE
		Aeolian	Beach	Lake	Alluvial					
UPPER UNIT	ZONE 3	Coversands Unit 3 Unit 2 Unit 1 (4,200-4,800 BP)	-	Organic Clays	Gravels	Low	Low aquatics Reduced NAP Increased *Eucalyptus*	Eucalypt Savannah	Warm Summers, Cool Winters.	Holocene
	ZONE 2		-	Organic Clays		Low	Low aquatics High NAP Low AP	Closed Grassland-Steppe	Warm Summers, Cold Winters.	Upper Pleistocene (See Text for Alternatives)
	ZONE 1	Sand	Sands Gravels	Inorganic Clays	Sands Gravels	High	High Aquatics Low NAP High-wind AP	Open Grassland-Steppe	Cool Summers, Cold Winters.	
Middle Unit		Clay				Low	-	?	Warm Summers, Cool Winters,	
		(?)	Gravel Beach	Clays	Sands Gravels	High	-	Grassland (?)	Cold, windy (?)	
Lower Unit		(?)	(?)	Clay	Sands Gravels	High	-	(?)	(?)	

The maximum extent of the former lake did not greatly exceed the margins of the present lake floor as there is no evidence of higher shorelines and/or terraces around the basin. The period of high water levels may have been followed by desiccation and weathering, but evidence of profile development was not observed in the lake sediments. Alternatively, the Lower Unit facies could pass directly into those of the Middle Unit without any change in size or level of the lake. The high water levels necessary for lacustrine sedimentation could have resulted from either an increase in precipitation, or more likely, from a reduction in evaporation with the same or even reduced precipitation.

The age relations and exact stratigraphic associations of the Middle Unit facies are uncertain. Since the deposits postdate weathering of the late Tertiary basalt which underlies the basin, it is likely that this period of lacustrine deposition occurred in the Pleistocene and probably during the upper part of this epoch. Without further stratigraphic evidence, the age of the Lower Unit sediments cannot be more precisely determined.

Middle Unit Sequence - The facies of the Middle Unit indicate renewed lacustrine sedimentation during a second high lake stage. Alluvial sands and gravels were fed into the lake via the fan and by slopewash, and a thick sequence of fine grained lacustrine sediments accumulated in the center of the basin. Erosion around the margins of the lake is clearly indicated by the presence of rounded ironstone gravel in the alluvial and beach sediments. This material was derived from either local basaltic soils or from phinthite reworked from the Tertiary sediments; or both.

The fine to very fine quartz sand which composes most of the Middle Unit alluvial and beach facies has no source in the local area and is apparently derived from outside the catchment. This conclusion, important in explaining much of the environmental history of the lake, is strongly supported by the seismic profiles and the geologic relations in the basin and its catchment.

The large amounts of quartz sand appear to be derived from the deflation of reworked Triassic sandstones deposited in the Birralee Valley west of the lake. Since the basalt ridge to the west separates the lake catchment from the valley, the quartz sand was most likely transported across the divide by strong west to northwesterly winds. Running water redeposited and concentrated the aeolian sand in the fan as the alluvium is locally bedded into lenses containing ironstone gravel.

The Birralee floodplain only partially provided the source of the Middle Unit sediments and the lacustrine clays in the center of the lake basin are derived from basalt regolith material washed into the lake by runoff from the margins. The beach gravels, also derived from regolith material or plinthite, were most likely transported to,and redeposited on the eastern margins of the lake by waves generated by currents under the influence of west to northwesterly winds.

Paleoecological information from the Middle Unit facies is not available and the environmental conditions which prevailed during this high lake stage can only be inferred from limited stratigraphic evidence. High water levels could have resulted from either an increase in precipitation, or more likely from a reduction in evaporation combined with either similar or reduced precipitation totals. Higher precipitation would tend to increase the density of the vegetation cover around the basin and result in greater slope stability. These conditions seem unlikely as the erosion and transport of slope material into the lake would necessitate some reduction in the herbaceous vegetation around the basin. Similarly , the deflation of fine sand from the Birralee Valley to the lake implies a reduction in vegetation on the divide and in the catchment.

Deposition of the Middle Unit lacustrine sediments probably occurred in a fairly open environment characterized by a lower evaporation regime. These conditions would be necessary to maintain high water tables in the basin and insure an adequate supply of runoff from the catchment. Lower evaporation rates, especially during the summer months, are related to a colder climate than present. Colder temperatures would effectively limit the vegetation cover and greatly increase the likelihood of slope erosion and aeolian activity.

The high water stage was followed by at least partial drying of the lake with deposition of the basal aeolian sandy clay in the lunette. The aeolian member forms a transverse dune at the base of the lunette which unconformably truncates and overlies the Middle Unit beach. The apparent high clay content and indistinct pelletal structure observed in the deposit suggests that the aeolian sediments consist partially of clay aggregates deflated from the exposed lake floor.

Most theories of clay dune genesis, based on modern analogs, require a combination of saline conditions and a seasonally exposed lake floor and beach adjacent to the dune (Bowler, 1973a; Price, 1963). Seasonal exposure of the lake floor with salt efflorescence favors the production of clay aggregates, and the saline conditions inhibit vegetation colonization on the exposed flats. Under these specialized conditions, clay aggregates are then deflated by unidirectional winds and are deposited on the leeward margins of the basin.

Two phases of deflation are recognized from a study of coastal mudflats in Texas by Price and Kornicker (1961). In the first, mudcrack polygon laminae are broken down when separated by wind as the particles are transported to the shore. A second phase occurs as the exposed sediments become granulated by efflorescence. The aggregates are transported by surface creep and saltation, and a transverse dune is built by seasonal increments of pelletal clay and sand trapped by marginal vegetation. Seasonal moisture stabilizes the aggregates and prevents further downwind movement.

The Middle Unit lunette sediments seem to have been deposited in a similar manner, and in a climate characterized by relatively warm temperatures and high evaporation rates. Clay dune formation probably occurred in summers when falling water levels in the basin reached a critical limit due to the deficiency between seasonal additions of water and the evaporation loss. The form and orientation of the dune indicates that the periods of deflation occurred under a northwesterly wind regime, and wind velocities from this general direction may have been greater, particularly during summer months.

Groundsurface stability and weathering may have occurred after lunette formation, but there is no conclusive evidence of soil development in the dune other than the brown coloration near the top of the deposit. This could have resulted from oxidation of iron compounds during weathering and there is evidence of pedogenic alteration in the alluvial and beach facies. Weathering of the dune, if it occurred, most likely took place in a relatively warm environment and humidity may have been higher.

The ages of the Middle Unit high lake stage and subsequent period of desiccation are uncertain. Since most of the smaller lakes in the Midlands are dry throughout much of the year, high water levels in the past are related to a colder climate when evaporation was lower and/or discharges into the basin were higher. The thickness and lateral extent of the Middle Unit lacustrine sediments suggest a prolonged period of deposition when regional temperatures in the Midlands were lower. These conditions are most reasonably associated with a major period of glaciation in the highlands of Tasmania. The factors necessary for lunette formation indicate a transition from a cold climate regime to one of rising temperatures and evaporation loss from the basin (Bowler, 1971). Paleoclimatic conditions of this nature are probably associated with either a warm interglacial or interstadial period.

The same two hypotheses which were advanced to explain the stratigraphic position of the lower sequence of aeolian and alluvial fan deposits in the lower Derwent Valley also may apply to the Middle Unit succession at Crown Lagoon. Based on this line of reasoning, the high lake stage could have occurred during either the Penultimate Glaciation or an early stadial period in the Last Glacial Stage. Similarily, desiccation and clay dune formation could have taken place either during the Last Interglacial Stage or an interstadial period of the last glaciation.

The evidence presently available is not sufficient to demonstrate which hypothesis is correct and either is possible. However, if the initial period of alluvial fan deposition in the lower Derwent Valley occurred during the early part of the Last Glacial Stage as was suggested in Chapter 7, then it is reasonable to assume that the Middle Unit high lake stage was broadly contemporaneous. If this correlation is valid, then the period of clay dune formation probably occurred during an interstadial of the Last Glacial Stage.

Upper Unit - The period of desiccation and clay dune formation was followed by renewed lacustrine sedimentation cumulating with the deposition of the Upper Unit facies. These deposits laterally intergrade across the basin and form a sedimentary series which in many respects resembles that of the Middle Unit. Since considerably more environmental data are available about the origin of the Upper Unit sediments, this portion of the chapter is divided into four sections which evaluate the stratigraphic relations, pollen analysis, soil profile development and coversand units of the lunette.

a. Stratigraphic Relations - The Upper Unit facies, consisting of alluvial, lacustrine and aeolian sediments, were deposited during the last major period of high water levels in the lake. The alluvial fan, incorporating reworked quartz sand and ironstone gravel, was again the depositional site of material eroded from both the adjacent Birralee Valley and the local catchment. The fine quartz sand in the alluvium, as in the Middle Unit equivalent, was derived from unconsolidated Triassic sands deflated across the divide by winds with a strong westerly component. The sand, and the locally derived ironstone gravel, was concentrated in the alluvial fan by running water and fed into the lake.

The deflation of sand from the Birralee Valley lake catchment would be favored by at least a seasonal reduction in vegetation density on the divide. This area is now covered by a thick mat of herbaceous vegetation (mainly *Poa spp.*) with a few trees, and there is no evidence of contemporary aeolian erosion, except on sandstone outcrops disturbed by grazing animals. The deflation of sand across the divide does not necessarily imply a landscape totally devoid of vegetation, but some reduction in grass cover seems likely to have occurred.

The deflation source would have been sandy floodplain material deposited in the Birralee Valley. The present valley is relatively broad, but only supports a small ephemeral stream channel. Subsurface data on the depth and type of alluvial material is not available, but fine quartz sand occurs in shallow exposures and in auger holes up to three meters in depth along the entire length of the valley. The present channel seems underfit in relation to the breadth of the valley and former periods of aggradation could have occurred in a fluvial regime characterized by relatively heavy sediment loads, possibly being transported in a braided system. If this were the case, periods of deflation most likely occurred seasonally in the absence of vegetation as the alluvium became dry enough to be transported by the prevailing westerly winds.

The Upper Unit alluvial member grades into the lacustrine clays deposited across the center of the basin. These sediments, up to 5 m thick, are derived mainly from slopewash erosion of basalt regolith from the margins of the lake. The thickness of the lake clays, combined with their low nitrogen content and absence of visible organic matter, suggests deposition in oligiotrophic conditions over a prolonged interval of time. The very fine quartz sand which occurs in these clays is probably derived from air-fall deposition during periods of aeolian erosion and sand transport from the Birralee Valley.

The predominantly sandy beach deposited along the eastern margins of the lake accumulated through wave action generated by strong west to northwesterly winds. The beach appears to grade directly into the sandy lunette sediments which unconformably overlie the Middle Unit clay dune. The fine aeolian sands were deposited by west to northwesterly winds and seem to have accumulated mainly through beach deflation during the high lake stage in a manner similar to that described by Bowler (1971) for the sand lunette members in the Willandra paleolake system.

However, the apparent textural bimodality of the Upper Unit lunette sediments is not fully consistent with an origin of active beach deflation as reported by Bowler. Previously published information on the sedimentary textures of clay dunes is relatively limited. Bowler (1973) has reported that the clay content in selected dunes ranges from about 66 to 77 percent in Texas examples, and from 22 to 77 percent in those from Australia. The clay content in the Upper Unit lunette sands ranges from 18.56 percent in the upper portion of the deposit to 10.31 percent near the base.

While the low abundance of clay in the Upper Unit lunette sands supports a predominantly sandy deflation source, such as the beach, there is the possibility that some or all of the clay fraction was derived from the deflation of fine-grained lacustrine sediments exposed on the dry lake floor. This interpretation would place the period of lunette deposition after water levels began to drop, and not during the high lake stage.

This conclusion seems unlikely as there is no stratigraphic evidence to indicate a hiatus between the period of beach deposition and that of the aeolian sands in the lunette. In fact, several lines of independent evidence argue against the possibility that the dune formed during the subsequent phase of lake floor exposure. First, the pollen evidence from Zone 2, corresponding with the low water period of the lake, suggests that much of the dry lake floor was vegetated, probably with grasses. This conclusion is also supported by the higher nitrogen values in the upper lake sediments which suggest a greater vegetation density in the basin. In this regard, the presence of vegetation on the lake floor would seriously limit the production of clay aggregates and greatly decrease the potential for aeolian erosion.

Second, the evidence of soil profile development in the lunette sands suggests that most, if not all, of the clay fraction in the deposit is derived from pedogenic processes and not inherited. This conclusion is supported by the clay depth function, the geochemical evidence of oxidation, and the structural characteristics observed in the lunette soil profile.

Hence, there is no conclusive geomorphic, biostratigraphic or pedologic evidence to indicate that the Upper Unit lunette sands were derived from the deflation of clay aggregates or other fine material exposed on the dry lake floor. The only technique which could differentiate any wind-transported clay in the deposit from that formed during pedogenesis would be micromorphological analysis, and this method might not resolve the question. The evidence available in this study indicates that most, if not all, of the Upper Unit lunette sediments at Crown Lagoon originated from the deflation of beach material synchronously deposited during the high lake stage.

b. Pollen Analysis - The pollen record for the Upper Unit high lake stage is derived from a single core and only spans the later period of lacustrine sedimentation in the basin. The fragmentary nature of the evidence only lends itself to broad paleoecological inferences until more data are available from other lake basins in the Midlands. With these limitations in mind, the pollen record must be cautiously interpreted, and the sequence of vegetation and inferred climatic changes presented here is tentative.

The most significant feature of the Zone 1 assemblage is the relatively high values of aquatic species, especially *Myriophyllum*, concurrent with very low abundances of most arboreal pollen types. The assemblage is markedly different from the modern surface and pond samples, and clearly indicates some magnitude of vegetation change during lacustrine deposition.

The predominance of aquatic pollen in the first sum acts to reduce the relative importance of all other types and most likely reflects low pollen productivity of strictly local NAP sources and/or a much reduced vegetation cover around the basin. This conclusion is partially supported by the abundance of wind-pollinated arboreal species in the second sum. Several possibilities could explain the abundance of *Phyllocladus*, a wind-pollinated rainforest species, in the second sum, but only two are likely: 1) the close proximity of these trees to the site during lacustrine deposition; or 2) the influx of long-distance, wind transported pollen combined with low local pollen productivity and/or a reduced vegetation cover around the lake.

In the first, the expansion of any type of rainforest community into the Midlands at this time would increase the absolute pollen representation of specific arboreal species in the record. A forest expansion of this nature would most likely accompany a climatic shift towards cooler (?), but especially more humid conditions with precipitation totals theoretically exceeding 1000 mm per year (Jackson, 1968). However, more humid conditions would increase the density of the local non-aquatic plant cover and its pollen representation, and statistically reduce the relative abundance of wind-pollinated AP in the sum (Mehringer, 1967). The low frequencies of grass and composite pollen in Zone 1 do not support this conclusion, but rather suggest a relatively open and possibly disturbed local environment.

In addition, a much greater variety of rainforest species should be present in the assemblage had such a displacement occurred. However, when compared with the total number of arboreal species found in fossil and modern samples from rainforest areas (Colhoun, pers. comm.), the Zone 1 assemblage contains only a small variety and all are wind-pollinated. *Eucryphia* is absent and the relatively few examples of *Nothofagus* pollen are badly damaged and may be redeposited. These arguments indicate that the rainforest component in the Zone 1 assemblage is most likely wind-transported and that there is no certain evidence to support an expansion of rainforest into the area during the high lake stage.

The vegetation patterns inferred from the assemblage are difficult to reconstruct and the strong possibility exists that an extinct community is involved. The abundance of *Myriophyllum*, a free floating or rooted herb, indicates freshwater, oligiotrophic conditions throughout the zone; a conclusion which is also supported by the low nitrogen values in the lower part of the core. The aquatics could not have formed closed mats of rooted plants in the lake as the sediments in this case would have been more organic and probably much more varied in pollen composition. Rooted aquatics were apparently absent from the eastern margins of the lake as their presence here in abundance would have limited wave action responsible for beach deposition.

The varying amounts of *Eucalyptus* in Zone 1 indicate either a local tree distribution, or its pollen may be partially or entirely derived by wind transport. *Eucalyptus* pollen cannot as yet be identified below the genus level with any degree of certainty and its presence here is probably not reliable as a definite indicator of ecological conditions. However, the ratio of *Eucalyptus*/Gramineae + Compositae is generally less than the modern values, especially in the upper part of the Zone; this factor alone suggests a tree density equal to or less than that of the modern eucalypt savannah. *Casuarina* pollen is also present in significantly higher proportions than in the modern samples and its abundance suggests greater aridity, especially at upland sites.

The frequency of cheno-ams in the core is problematic as this pollen type is rare in the modern samples. The sharp level-to-level variations strongly suggest a local distribution of these plants around the lake. Cheno-ams cannot be cited as an indicator of saline conditions in the Zone 1 lake because the abundance of *Myriophyllum* proves freshwater conditions. Jackson (pers. comm.) has suggested that high proportions of cheno-ams in fossil inland sequences could indicate relatively cold conditions, but this conclusion is uncertain and can be validated only by additional research. Cheno-ams may also indicate erosion and a frequently disturbed landscape (Martin, 1961), but this inference is unproven in the Australian context.

The Zone 1 assemblage suggests that the fossil vegetation community around the lake was a relatively open grassland-steppe. Eucalypts were probably absent, or limited to frost resistent species, such as *E. pauciflora*. The relatively low NAP component in the assemblage implies a reduction in local vegetation cover, especially grasses. These data suggest a colder environment than present since lower temperatures would limit vegetation cover and increase both the likelihood and effectiveness of catchment erosion. A reduction in vegetation would lower soil infiltration rates, increase overland flow and the erosion of regolith material (Kirkby, 1969). The combination of these factors would result in increased slope erosion and the accumulation of lacustrine sediments.

Lower temperatures and evaporation rates, especially in spring and summer, would be required to maintain high water levels in the lake. Precipitation, or at least precipitation directly available for plant growth, does not appear to have been any higher than present or it would have resulted in an increase in local plant cover; a conclusion contrary to the pollen and stratigraphic evidence. The evidence does not directly imply seasonal variability of climate, but summers were likely to have been cooler than present. Winters were probably significantly colder with much of the precipitation in the form of snow.

Given colder temperatures, the surface of the lake would have been frozen throughout much of the winter. Consequently, the main periods of lacustrine sedimentation probably occurred in the spring and summer months when concentrated runoff in the form of snowmelt was available. Aeolian erosion is likely to have taken place during these seasons as the plant cover around the lake and on the divide would have been at a minimum.

The Zone 1 assemblage and its stratigraphic associations strongly imply a cold winter-cool summer climatic regime, most likely corresponding with a glacial stade in the Tasmanian highlands. While the precise age of the assemblage cannot be determined, its inferred vegetation characteristics and relative stratigraphic position suggest deposition at or near the maximum of the Last Glacial Stage.

The high water stage of Zone 1 was followed by at least partial drying of the lake. The sharp reduction in aquatic pollen concurrent with the rise in Gramineae in Zone 2 supports this conclusion and indicates a major hydrologic change in the basin from high water conditions to a more intermittent and shallower body of water. This transition could have occurred relatively quickly given the sharp pollen fluctuations and increased nitrogen values in the upper 70 cm of the core.

The basin probably contained a more mesotrophic marsh by this time with most of the lake floor exposed for long periods. This conclusion is suggested by the abundance of Gramineae, and the presence of *Plantago* and Caryophyllaceae pollen in Zone 2. The low frequency of aquatic pollen, especially *Myriophyllum* does, however, suggest some standing water in the basin, perhaps accumulating seasonally in central pools.

The transition between Zone 1 and 2 is marked by a reduction in arboreal species and the *Eucalyptus*/Gramineae + Compositae ratio is at its lowest level. The very low frequency of *Eucalyptus* pollen may be partially controlled by the relative abundance of the NAP types, especially Gramineae. However, this relationship seems unlikely as the same constraining effect does not occur in the modern samples, even though the grass percentages are as high as in Zone 2.

The abundance of Gramineae in Zone 2 suggests the establishment and maintenance of a grass cover in and around the basin. Gramineae pollen is probably over-represented and the assemblage may not entirely reflect either the floristic composition or structure of the local vegetation community. However, relative to the modern data, the Zone 2 assemblage strongly supports the conclusion that the vegetation was a "closed" grassland-steppe with few or no trees.

Frequent burning is a factor which could effectively reduce the local tree density and maintain a grassland community (Jackson, 1965; Odum, 1959). The finely divided charcoal above 50 cm in the core does suggest fire control by either natural causes or Aboriginal land-use. However, the frequency of burning cannot be assessed from the presence of charcoal alone and this factor would be of critical importance in limiting tree growth and propagation. The rise in grass pollen and evidence of lake drying begins between 90-70 cm in the core, but there is little or no charcoal in slides below 50 cm. This relationship indicates that the grassland expansion began prior to the advent of burning and that the Zone 2 community is probably related to environmental factors other than fire.

In the Midlands the most important climatic factors influencing grass cover and limiting the distribution of eucalypt species are frost frequency and aridity (Jackson, 1973; Kirkpatrick, pers. comm.). In this respect a seasonal moisture deficit, especially during the summer months may have been important in limiting the full expansion of eucalypts into the area during Zone 2. This factor, combined with high frost frequencies in winter, may explain the relatively low tree density inferred from the Zone 2 assemblage. However, no change in tree density need necessarily have occurred between Zones 1 and 2, even though the relative pollen frequencies changed.

If frost was one of the limiting factors of eucalypt growth and propagation at these times, the most widespread species present would have been *E. pauciflora*, the dominant taxon in the area today. The present distribution of this non-endemic species in the Midlands is most likely a relic feature inherited from a colder climate with significantly higher frost frequencies than at present.

The hydrologic transition from the high lake levels of Zone 1 to the seasonal or intermittent water body inferred from Zone 2 is most likely due to a climatic change involving temperature and/or precipitation. Warmer summers would increase evaporation over the lake surface and produce a seasonal moisture deficit in the basin. Warmer temperatures, and a longer growing season, would increase the density and floristic composition of the herbaceous vegetation around the basin, a conclusion fully consistent with the pollen evidence from Zone 2 which suggests grassland expansion. An increased herbaceous cover would effectively reduce the rate of erosion and lead to higher infiltration rates and water storage in the regolith (Hudson and Jackson, 1959). In combination, these local hydrologic factors would reduce the level of water in the basin and restrict lacustrine sedimentation to isolated pools.

An increase in precipitation may have also occurred at this time, but higher summer temperatures and evaporation rates would still create a seasonal moisture deficit in the basin. Any drastic reduction in precipitation at this time seems unlikely as the presence of *Myriophyllum* and other aquatic pollen in Zone 2 suggests at least intermittent pools of fresh water in the lake. In addition, a marked soil deficit associated with very arid conditions would limit all vegetation growth; a conclusion contrary to the pollen evidence.

Thus, a trend towards higher summer temperatures and evaporation rates seems to be the major cause in explaining the drop in water level in the basin. Winter temperatures would have to remain at least as cold as in Zone 1 to effectively restrict eucalypt expansion into this portion of the Midlands. The age of the pollen assemblage cannot be precisely determined, but the general pattern of vegetation change inferred from the record suggests the beginning of a general climatic amelioration, most likely occurring near the end of the Last Glacial Stage in Tasmania.

The Zone 3 assemblage shows a trend towards continued low water levels with restricted lacustrine sedimentation in the basin. The high nitrogen values indicate relatively eutrophic conditions with increased organic sedimentation. The lake sediments deposited at this time appear to have accumulated slowly and bear no relationship to the older lacustrine and aeolian facies of the Upper Unit.

The increase in Cyperaceae pollen in Zone 3 suggests a seasonally inundated marsh throughout much of the period of deposition. The most significant feature of the assemblage is the marked increase in *Eucalyptus* pollen, especially in the upper portion of the zone. This change occurs synchronously with a reduction in the abundance of Gramineae pollen, and could have resulted from conditions limiting grass cover and its pollen representation.

However, any significant decrease in herbaceous ground cover at this time seems unlikely as sufficient water was available to maintain at least a seasonal marsh in the basin. Any increase in wind-transported eucalypt pollen seems equally unlikely given the very low abundance of other wind pollinated arboreal species in the record. The abundance of eucalypt pollen is most likely related to the establishment of an open sclerophyll woodland at or near the site, at the expense of the grassland inferred from

Zone 2. This conclusion is strongly supported by the relatively high *Eucalyptus*/Gramineae + Compositae ratios in Zone 3, with values approximating the modern community.

With the exception of the cheno-ams whose ecological significance is unknown, the Zone 3 assemblage is essentially similar to the modern surface samples. Eucalypt expansion, combined with the maintenance of a seasonal or intermittent marsh in the basin, most likely occurred with continued amelioration of climate during and following the Last Glacial Stage. The most important climatic parameters appear to have been a trend towards warmer winters with much reduced frost frequency. Summer temperatures probably became as warm as present and precipitation may have increased relative to the Zone 2 phase to permit intermittent flooding of the basin. The general characteristics and stratigraphic position of Zone 3 suggest that most, if not all, of the assemblage is of Holocene age.

c. Soil Profile Development - Weathering of the Upper Unit alluvial, beach and lunette sediments most likely began during Zone 2 after water levels in the basin began to fall, and continued throughout most of Zone 3. This conclusion is fully consistent with the pollen evidence which suggests grassland expansion with general groundsurface stability. In terms of gross macrostructure, the profiles on the Upper Unit facies show a similar degree of development, and appear to form a soil stratigraphic catena with respect to differences in texture and local drainage.

The dominant pedogenic processes which characterize these profiles include oxidation of iron compounds with either *in situ* and/or alluvial formation of clay minerals in the B horizon. These processes are implied from the depth function relations of texture, geochemistry and clay minerals observed in the lunette profile (Table 9).

The major clay minerals in the lunette profile are kaolinite and montmorillonite. Their relative abundance show an inverse relationship with profile depth, with kaolinite being predominant in the B horizon. This relationship suggests that the clays are primarily the result of profile weathering processes and are not inherited through aeolian transport. This conclusion is supported by the extractable iron and sesquioxide maxima in the upper portion of the deposit which indicate *in situ* alteration of ferromagnesian minerals in the B horizon. Only the general weathering sequence can be reconstructed. The evidence suggests weathering of feldspars to montmorillonite with subsequent formation of kaolinite. Ferrous iron, a probable by-product of this reaction, would have been oxidized in the B horizon to form an insoluble residue. Alternatively, ferrous iron could have been oxidized directly from the primary minerals without the production of clay minerals, although this possibility seems unlikely given the distribution of clay in the profile.

By comparison, the soil formed on the Upper Unit lunette sands closely resembles those formed on the sandsheets at Bridgewater, Old Beach and Glenfield in the Lower Derwent Valley (Unit 1), particularly in terms of macrostructure, horizon color and depth, and textural differentiation between horizons. Figure 27 shows the more detailed similarities and differences between the Crown Lagoon profile and that formed on the sandsheet at Bridgewater. Between soil horizons, both profiles show a nearly identical sesquioxide and clay mineral distribution. The main differences between the profiles are minor variations in proportions of clay and extractable iron oxide with depth. These appear to be insignificant when compared with the totals present in each deposit and could easily reflect experimental error, or more likely, the differences in parent material observed between the deposits.

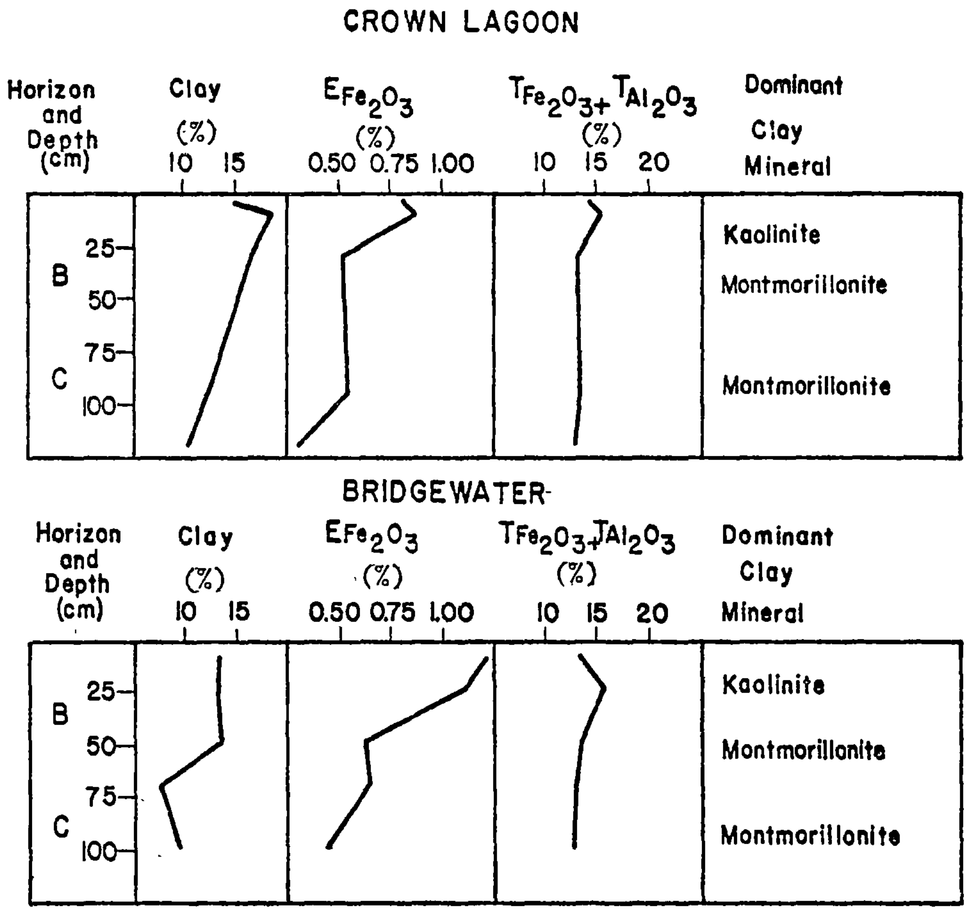


Figure 27. Selected profile characteristics of the Crown Lagoon Upper Unit lunette sands and the Bridgewater sandsheet (Unit 1)

Thus, a comparison of both the macrostructure and detailed geochemical properties of these profiles suggests a nearly equivalent degree of weathering and oxidation in the B horizons with respect to the differences in parent material. This relationship is a means of correlating the two deposits, and it suggests that both were weathered during the same general period of groundsurface stability. Since the pollen evidence from Crown Lagoon indicates the establishment of stable vegetation cover by at least Zone 3, weathering of the Upper Unit facies appears to have begun during the later part of the Last Glacial Stage and continued throughout the Holocene until profile truncation occurred.

d. Coversand Units - The surface horizons of the Upper Unit soil are missing and Unit 1 of the coversand sequence is only found overlying the truncated B horizons of the beach and lunette profiles. This indicates that the sands were derived from the aeolian reworking of the underlying A horizons. This conclusion is supported by the close modal similarity in grain size between the Upper Unit aeolian sands and that which composes Unit 1. The deflation and redistribution of the surface horizons by west or northwesterly winds resulted from multiple periods of localized vegetation destruction and groundsurface instability on the lunette.

The most likely agent responsible for site instability appears to have been Aboriginal man, acting independently of climatic controls favoring erosion in this situation. This conclusion is primarily based on the stratigraphic association of Unit 1 and the evidence of human occupation in the dune. An anthropogenic origin for the coversand units is further supported by the Zone 3 pollen assemblage which, while not precisely dated, contains no evidence of climatic aridity during the Holocene. In addition, the abundant charcoal in the upper 50 cm of Zone 3 suggests burning and surface disturbance by the Aboriginals throughout much of the Holocene record.

The mid-Holocene residents of Crown Lagoon may have been attracted to the marshy lagoon for its intermittent water resources and the potential for game animals. The bones of marsupials found in Unit 1 by Lourandos support this conclusion. The nature of the archeological evidence as reported by Lourandos suggests that the site was occupied by small groups of Aboriginals, mostly during hunting forays into the interior of the Midlands. In this respect, the sands of Unit 1 could have accumulated during several periods of occupation by the site-intensive activities of Aboriginals living on the surface of the lunette.

The very weak oxidation of iron compounds in the upper portion of the unit indicates a subsequent period of stability sometime after 4,200 BP. Stability may have coincided with site abandonment by the Aboriginals for reasons which are not fully understood. Younger hearths may be present elsewhere in the deposit and intermittent occupation may have continued to a later date. However, surface oxidation over most of the unit probably took place over a relatively long period as the rate of weathering in this type of deposit is more dependent on the pre-weathered nature of the parent material, rather than on other environmental factors.

The textural characteristics of this unit are nearly identical with those of the Unit 2 coversand unit at Glenfield (see Tables 4 and 11). Though slightly older at Crown Lagoon, these sediments are considered to be lithostratigraphic equivalents on the basis of their textural similarities and relative stratigraphic positions. The similar degree of oxidation in the upper 10 cm of both deposits further supports this conclusion, but stability occurred at slightly different times at each site.

The thin, organic sand lens, separating Units 1 and 2 in the coversand sequence, is apparently associated with a subsequent phase of occupation by the Aboriginals. The high flake density and large charcoal fragments in the lens suggest that it originated as a thin hearth incorporating sand disturbed from Unit 1. The lens, like its apparent equivalent at Glenfield, probably represents very brief re-occupation of the site, most likely somewhat before or at the time of European settlement.

Unit 2 unconformably overlies the surface of Unit 1 and was derived from the disturbance of the underlying sands and redeposited by westerly winds. The uniform dark color and finely divided charcoal in this unit suggest that the sands accumulated in the presence of organic matter and periodic burning. The time of deposition cannot be directly fixed, but the absence of archeological evidence in the unit suggests accumulation during European settlement.

The gravels on the alluvial fan may have also accumulated at this time, but the relationship of this unit to those in the coversand sequence is not certain. The gravels clearly post-date the final phase of deposition and weathering of the fan and appear to have been concentrated through localized erosion in the catchment. This unit probably accumulated as a direct result of European land clearance and plowing of the catchment.

Unit 3 unconformably overlies all of the aeolian units exposed on the lunette and contains ample evidence of European occupation. This unit is most likely derived by the aeolian redistribution of the underlying coversand units and appears to have formed by multiple periods of local surface instability caused by grazing animals.

In summary, a comparison of the stratigraphic and textural relations of the coversand units at Crown Lagoon with those at Glenfield in the lower Derwent Valley indicates that these sequences are nearly identical, and each was formed by the activities of Man. There is no independent evidence at either site to indicate that these units formed as a result of climatic aridity during the Holocene. Although formed at different times during the Holocene, the sequences reflect a similar type and intensity of human disturbance of the pre-existing groundsurface. The most significant feature of these deposits is that their formation results from human activity, independent of climatic controls favoring aridity.

II. WHITE LAGOON

Stratigraphic Sequence - Table 14 shows the sequence of depositional events and the inferred climatic reconstruction for the units exposed in the White Lagoon lunette. The oldest unit, exposed at the base of the lunette, is the alluvial gravel deposited on the dolerite. The gravels apparently form part of a bedload channel graded above the present level of the Blackman's river floodplain and may have been deposited during a period of high level aggradation in the master Macquarie drainage system.

Alluvial deposition was followed by at least local surface stability and weathering of the gravels. The thickness of rind development and red coloration of the matrix suggests a prolonged period of pedogenic alteration in a strongly oxidizing environment. Weathering probably occurred in a relatively warm climate with sufficient humidity to remove free carbonates from the matrix. Since the degree of rind development indicates very considerable age, the deposits could have been weathered during at least one interglacial stage, but the actual time of deposition is unknown. Correlation of this deposit with the Crown Lagoon lacustrine sequence is equally uncertain, but the gravels most likely pre-date the Middle Unit high lake stage by a considerable period of time.

Weathering of the alluvial gravels was followed by a period of aeolian erosion during which the Unit 2 sandy clay was deposited in the

TABLE 14

PROVISIONAL LATE QUATERNARY SEQUENCE FROM WHITE LAGOON

STRATIGRAPHIC UNIT	LAKE STAGE	CLIMATIC RECONSTRUCTION	GEOLOGIC AGE
	Low	Warm summers Cool winters	HOLOCENE
Aeolian clay (Unit 4)	Low	Warm summers Cold winters	UPPER PLEISTOCENE (See Text for Alternatives)
Aeolian sand (Unit 3)	High	Cool summers Cold Winters	
Aeolian sandy clay (Unit 2)	Low (?)	Warm summers Cold (?) winters	
Alluvial gravel (Unit 1)	(?)	(?)	

Soil

lunette by northwesterly winds. This unit is confined to the lunette ridge and it appears to be a clay dune variation derived from the deflation of fine-grained sediments once exposed in the basin west of the lunette. This conclusion is supported by the high clay content and weak pelletal structure observed in the dune which suggest that the original deposit was composed mainly of clay aggregates. The exact deflation source is unknown, but the aggregates may have been derived from a seasonally or intermittently dry lake floor, or alternatively from alluvial clays exposed on an old valley.

Whatever the source of material, the deflation of clay aggregates requires an unstable groundsurface largely devoid of vegetation cover. If the unit is derived by the deflation of intermittently exposed lacustrine sediments as seems likely, then drying of the lake basin could have occurred in a warm summer-cold winter climatic regime similar to that proposed for the Middle Unit clay lunette sediments at Crown Lagoon. The time of deposition cannot be determined, but the relative stratigraphic position of the unit suggests that it may be equivalent with the Middle Unit clay dune at Crown Lagoon. If this correlation is valid, Unit 2 at White Lagoon may have formed either near the end of the Penultimate Glacial Stage, or at the beginning of an interstadial period of the Last Glacial Stage.

Aeolian deposition was followed by surface stability and weathering of the dune. The dominant pedogenic processes inferred from this profile include oxidation of iron compounds with either *in situ* and/or illuvial formation of clay in the B horizon. Considering these characteristics and the degree of soil development on the deposit, pedogenesis may have occurred during a relatively long period of stability.

The relative degree of profile development on this deposit cannot be directly compared with the Middle Unit clay dune at Crown Lagoon since these sediments were only observed in a disturbed core section. However, the Middle Unit clay dune occupies the same relative stratigraphic position as does Unit 2 at White Lagoon, and it is reasonable to suggest that both deposits were exposed to pedogenic alteration during the same general period of stability.

On a regional basis, the Unit 2 profile at White Lagoon is considerably better developed than are those on the principal sandsheets in the lower Derwent Valley, and the Upper Unit soil facies at Crown Lagoon. By comparison, the profile more closely resembles those formed on the interstratified sandsheets at Red Gum and Lime Kiln Point, especially in terms of ped development and color differences between horizons (See Plates 21, 23 and 39). Since the relative degree of profile development is similar on all three deposits, it is likely that each was weathered during the same period of stability. If this correlation proves to be valid, then weathering of the Unit 2 profile at White Lagoon could have occurred during either the Last Interglacial Stage or an interstadial period of the Last Glacial Stage.

Weathering of the sandy clay was followed by a period of erosion during which the A and part of the B horizon of the soil profile were stripped. Intense wind scour could account for profile truncation given the irregular surface of the deposit. Truncation of the soil profile was followed by a period of lacustrine sedimentation in the basin with a small lake forming behind the eroded remnant of the lunette.

Climatically, the high lake stage seems unlikely to have resulted from any significant increase in precipitation as the basin lies directly in the rainshadow of the Central Plateau. The lake sediments are composed mainly of regolith material eroded from the local catchment, and this relationship implies some degree of slope instability and reduction in vegetation cover during lacustrine deposition. High water levels more likely associated with a lower temperature and/or evaporation regime, especially during the summer months. Given the relative stratigraphic position of the lacustrine sediments the high water stage is tentatively correlated with the Upper Unit Zone 1 lake at Crown Lagoon, and on this basis probably occurred near the maximum of the Last Glacial Stage.

The thin bed of aeolian sand (Unit 3) which locally overlies the eroded surface of Unit 2 in the lunette is probably derived from the deflation of beach material deposited during the high lake stage. The quartz sand component in the lens is coarser than that of Unit 2 and appears to be more similar in texture to the alluvial fan sediments deposited outside the margins of the basin. This relationship suggests that the aeolian sand lens, the inferred beach and the fan overflow sediments form a relatively continuous depositional series. Beach deflation under the influence of west to northwesterly winds could have occurred simultaneously during the periods of lake overflow caused by seasonal snowmelt. In this respect, the deposits are tentatively correlated with the Upper Unit alluvial, beach and aeolian facies at Crown Lagoon and are thought to have been deposited during the same general period of instability and slope erosion.

The high lake stage was followed by a period of desiccation leading to the deposition of the Unit 4 aeolian clay in the lunette. There is no evidence of soil profile development in the underlying sandy lens, which suggests rapid burial by the aeolian clay. Given the small size of the basin, this relationship probably reflects the hydrologic sensitiveness of the lake to local environmental changes, rather than a particularly rapid major climatic change. However, the clay unit was deflated by relatively strong northwesterly winds and the sediments are clearly derived from the depression in the lake floor.

The granular structure of the clay indicates that most if not all of the deposit is composed of clay aggregates derived by the erosion of fine grained sediments exposed on the dry lake surface. The abundance of carbonate nodules on the lake floor adjacent to the depression suggest that alkaline conditions prevailed in the basin during periods of deflation. The basin was a sediment trap to concentrate salts derived locally from the evaporite lenses in the Triassic sandstones. Intermittent or seasonal drying of the basin, resulting in saturation and salt precipitation, would provide the ideal environment for the production of clay aggregates (Bowler, 1973). The formation of the upper clay dune in the lunette most likely resulted from an increase in seasonal temperatures and evaporation rates. This period of low water levels with clay dune formation is thought to have been broadly synchronous with that recorded from the Zone 2 pollen assemblage at Crown Lagoon during the latter part of the Last Glacial Stage.

The age of lake drying cannot be determined from either site, but the event probably occurred in both areas sometime prior to 9,000 BP. This conclusion is based on a single radiocarbon date of 9,550 ± 200 BP (GaK-2239) from the base of peat, 2.5 m thick, in Lake Tiberias, some 35 km south of White Lagoon (Goode, pers. comm.). This lake is bordered on its southeastern margin by an extensive source bordering dune consisting of sandy clays and clays. The date provides a minimum age of drying in this basin and overlies inorganic lacustrine clays similar to those observed at both Crown Lagoon and White Lagoon.

During this period a clay dune formed at White Lagoon, but not at Crown Lagoon. Conditions on the lake floor at Crown Lagoon do not appear to have been saline enough to inhibit vegetation growth as indicated by the abundance of Gramineae in the Zone 2 assemblage. The salinity tolerance of grasses vary widely (Russell, 1961), but *Themeda* and *Poa*, the most prevalent species in the Midlands, are not common in or around saline lakes (Townrow, 1969). In addition, the concentration of salts in a basin depends primarily on the effluent from the catchment. The Crown Lagoon catchment drains basalt and very little dolerite, and the Triassic component is mainly in the form of aeolian quartz sand. The absence of carbonate of other precipitated salts in the Upper Unit lake sediments suggest that only low concentrations were available or added to the basin. Low salinities in the basin would effectively limit the production of clay aggregates and the grass cover on the lake floor would protect the surface from deflation.

In contrast, potentially large quantities of salts are available to the White Lagoon basin from the local catchment. During seasonal or intermittent drying of the basin, high salt concentrations would favor the production of clay aggregates in the fine grained lake sediments through efflorescence and inhibit vegetation colonization of the exposed littoral zone. As stated earlier, these conditions, concurrent with high evaporation rates and strong northwesterly winds, would be the ideal environment for the production and deflation of clay aggregates.

The deposition of the upper aeolian clay at White Lagoon was followed by stability and soil development in the dune. The dominant pedogenic processes include accumulation of organic matter in the A horizon with leaching and redeposition of free carbonate in the solum. The profile shows no evidence of a B horizon and clay illuviation appears to have been minimal. The well developed ped structure reflects the high clay content of the parent material and the development of stress cutans suggests intermittent wetting and drying of the groundsurface.

The profile closely resembles a chernozem or black earth (Stace, et al., 1968) and probably formed in an environment similar to the present, which is marginally continental. The relative stratigraphic position of the profile is the same as the Upper Unit soil facies at Crown Lagoon, and it most likely began forming during the same general period of stability at the end of the Last Glacial Stage and throughout the Holocene.

Correlations between these and other sites are strictly tentative and are based on rather limited stratigraphic and palynologic evidence. However, the sequence of lacustrine-aeolian events between Crown Lagoon and White Lagoon is relatively similar and the major depositional phases seem to have been broadly synchronous. In the following chapter the evidence from the lower Derwent and Midlands sites will be evaluated and compared in discussion of the paleogeographical environment in southeastern Tasmania.

PART IV

THE PALEOGEOGRAPHIC ENVIRONMENT

Synthesis, Correlation, and Conclusions

CHAPTER 11

THE PALEOGEOGRAPHIC ENVIRONMENT: SYNTHESIS AND CORRELATION

This chapter organizes the evidence from the lower Derwent and Midlands sites into an integrated paleogeographical model of climatic change in southeastern Tasmania during the late Quaternary period. The first part deals principally with the correlation of events between the two areas, and is supplemented with additional data from the glaciated Highlands to place the local evidence into a broader regional context. The concluding part contains a brief comparison of the evidence with that of relevant studies from the Mainland.

<u>Problems of Correlation</u> - There are numerous problems in establishing the correlation and age relations of events recorded in the lower Derwent and Midlands sites. Principally, a radiometric chronology cannot as yet be established for many of the major depositional events, and the time-stratigraphic position of these units remains unresolved. Secondly, the aeolian deposits of the lower Derwent and elsewhere in southeastern Tasmania are related to fluvial regimes, while those of the lunettes in the Midlands are associated with lacustrine fluctuations; and inherent difficulties exist in correlating deposits from these dissimilar environments. Finally, the geomorphic effects associated with human occupation can result in the formation of new landforms, independent of climatic

controls, and these may be difficult to distinguish from those created by natural processes.

With these considerations in mind, Table 15 synthesizes the major events recorded from both areas into a provisional late Quaternary sequence for southeastern Tasmania. This table presents two hypotheses to explain the age of the deposits in the lower part of the sequence as sufficient local and regional evidence is not yet available to conclusively demonstrate either to be correct. The means of correlation used is the relative stratigraphic position of the deposits, their geomorphic interpretations and the available radiometric dates. The relative degree of soil profile development is also used to subdivide the sequences and as a limited means of correlation. The pollen evidence from Crown Lagoon, while from a single, undated core, is used as a paleoecological guide to evaluate the magnitude of vegetation change in the upper part of the sequence and to make inferences about the lower.

Pleistocene Sequence - Assuming tectonic stability, the high level alluvial and estuarine terrace deposits at Old Beach, Bridgewater and in the lower Jordan Valley provide tentative evidence to support local aggradation during a high sealevel or interglacial period. These sediments were deposited during a positive sealevel oscillation of up to 15 m in this portion of the Derwent estuary and its tributaries. The elevation of the terraces relative to present sealevel suggests a baselevel transgression within the approximate range known for the Last Interglacial

TABLE 15

PROVISIONAL LATE QUATERNARY SEQUENCES FROM SOUTHEASTERN TASMANIA

	LOWER DERWENT VALLEY		MIDLANDS SITES		PALEOCLIMATE			
AGE	SINGLE GLACIAL CYCLE	DOUBLE GLACIAL CYCLE	SINGLE GLACIAL CYCLE	DOUBLE GLACIAL CYCLE	SINGLE CYCLE		DOUBLE CYCLE	
					Sum.	Win.	Sum.	Win.
Holocene	Coversands	Coversands	Coversands	Coversands	Warm	Cool	Warm	Cool
	(Soil)	(Soil)	(Soil)	(Soil)				
Last Glacial Stage	Upper Aeolian Sandsheets Slope Deposits Alluvial Fans	Upper Aeolian Sandsheets Slope Deposits Alluvial Fans	Lunette Clays Lunette Sands Upper Unit High- Lake Stage	Lunette Clays Lunette Sands Upper Unit High- Lake Stage	Warm Cool	Cool Cold	Warm Cool	Cool Cold
	(Soil)	(?)	(Soil)	(?)	Warm	Cool	(?)	
	Lower Aeolian Sandsheets Slope Deposits Alluvial Fans	Slope Deposits (?)	Lunette Clays Middle Unit High- Lake Stage	(?)	Warm Cool	Cold Cold	(?)	
Last Interglacial Stage	(Soil) Jordan, Old Beach and Bridgewater Alluvial Sands and Gravels	(Soil) Jordan, Old Beach and Bridgewater Alluvial Sands and Gravels	(Soil) White Lagoon Gravels (?)	(Soil)	Warm	Cool	Warm	Cool
Penultimate Glacial Stage	(?)	Lower Aeolian Sandsheets Slope Deposits Alluvial Fans	Lower Unit High- Lake Stage	Lunette Clays Middle Unit High- Lake Stage White Lagoon Gravels (?)	(?)		Warm Cool	Cool Cold

Stage (Davies, 1959; Flint, 1971). The period of estuarine infilling seems to have been broadly synchronous with the deposition of other apparently similar, eustatic marine, estuarine and alluvial sediment around the island, which are also believed to be of Last Interglacial age (Colhoun, pers. comm.). This interpretation is supported by the general continuity in height of the terraces examined in this study and their relative degree of soil development as compared with other deposits of this probable age.

Stability and weathering followed the period of alluvial and estuarine deposition in the lower Derwent and its tributaries. The overall profile characteristics suggest weathering in a relatively humid environment with temperatures and precipitation probably comparable to that of the present temperate marine climate. Weathering of the terrace deposits may have occurred over a long period of time because the profiles are strongly developed, and the gravels incorporated in the alluvium have well-formed rinds.

The period of high level aggradation at the lower Derwent sites cannot be correlated with the Midlands lacustrine sequences with any degree of certainty. A possible equivalent could be the alluvial gravels underlying the lunette at White Lagoon, but this deposit may be older than high level sediments at Old Beach and in the lower Derwent Valley.

The relative degree of weathering on the dolerite gravels at White Lagoon is roughly similar to that found on the high level alluvial gravels at the lower Derwent sites. If a correlation based on the thickness of weathering rinds is valid, the similarities in weathering between these deposits could indicate that each was pedogenically altered during the same general period of stability. However, this relationship cannot be supported by other lines of independent evidence, and the exact age of the White Lagoon gravels is unknown.

In the lower Derwent Valley, weathering of the high level alluvial sediments was followed by erosion and terrace formation. The position and elevation of the terrace remnants suggest that valley trenching resulted from a lowering in baselevel, probably during the glacio-eustatic lowering of sealevel which occurred at the beginning of the Last Glacial Stage. In the lower Jordan, the downcutting channel removed most of the original fill by lateral incision until the river was superimposed on the bedrock floor of the valley. The high level deltaic sediments at the Jordan confluence were similarly removed, with only thin fragments being preserved along the margins of the estuary and on rock terraces. Erosion probably continued until a stable baselevel was reached in relation to sealevel lowering and it appears likely that the emerged Derwent channel was about 30 m below present sealevel near the Jordan confluence.

As noted in Table 15, the lower sequence deposits from the lower Derwent and Midlands sites may be interpreted as occurring within the Last Glacial Stage or in two distinct glacial stages. The problem in correlation lies in establishing the time of deposition for the lower alluvial fan, lacustrine and aeolian sediments. This portion of the record undoubtedly lies beyond the range of radiocarbon dating, and the deposits can only be evaluated on the basis of their relative stratigraphic, geomorphic and pedologic criteria.

Both the upper and lower alluvial fan sequences in the lower Derwent Valley were deposited at a time of lower sealevel in the estuary. The fans reflect widespread catchment instability with at least a local reduction in vegetation cover on the upper slopes of the valley, and their deposition is consistent with either warm, semiarid, or periglacial conditions. A warm climatic origin for the fans seems very unlikely for the following reasons: 1) the fans are essentially inactive in the modern environment; 2) there is a strongly implied genetic relationship between the caliber and extent of the fan sediments and those of the known periglacial solifluction deposits which mantle the upper slopes of the valley; 3) the gradient of the fans indicates a low sealevel (glacial) age for deposition; and 4) radiocarbon dates from the Rocky Cape fan on the northwest coast indicate at least one period of fan deposition occurred before and during the maximum of the Last Glacial Stage in Tasmania (Colhoun, pers. comm.). This reasoning, while based on limited evidence, indicates that the cycles of slope instability and fan deposition closely correspond with local periglacial conditions in response to one or more glacial stages.

The oldest known alluvial fans at Red Gum and Lime Kiln Point in the Derwent Valley were most likely deposited under at least marginal, periglacial conditions in a colder climate than present. Reduced temperatures, especially in winter months, would almost certainly cause a significant portion of the precipitation falling on the upper slopes, and probably at lower elevations in the valley, to be in the form of snow. Colder temperatures would effectively alter the structure and reduce the density of the vegetation, thus favoring instability and slope erosion in the catchments. Seasonal snowmelt was the most likely source of water for episodic mass movement at higher elevations and fan deposition in the lower valleys.

A secular reduction in temperature, resulting in the production of solifluction debris in the lower Derwent region, would also affect the hydrologic balance of the lake basins in the Midlands by lowering summer evaporation rates, and would result in high lake levels. If this relationship is valid, the Middle Unit high lake stage at Crown Lagoon was probably contemporaneous with the initial period of slope instability and fan deposition in the lower Derwent area. The stratigraphic inferences concerning the depositional environment of the Middle Unit lake sediments support this conclusion and suggest that the high lake stage occurred during a period of reduced vegetation cover and local slope instability. High water levels in the lakes of the Midlands are more consistent with a reduced temperature and evaporation regime, rather than any increase in annual precipitation. The correlation of the Lower Unit lacustrine phase with an older, cold climate phase is possible,but uncertain. However, as suggested in a previous chapter, the Lower Unit lake sediments may simply grade into those of the Middle Unit without an intervening stratigraphic hiatus.

The initial period of alluvial fan deposition in the lower Derwent Valley was followed by an interval of aeolian activity during which the sandsheets at Red Gum and Lime Kiln Point were formed. Fan stabilization at these sites implies a greater degree of catchment stability, probably associated with a general climatic warming trend and revegetation of the upper slopes. The sandsheets were derived from the deflation of sandy floodplain material from the emerged Derwent by westerly winds channelled down the valley. The floodplain at this time cannot be reconstructed as any remaining alluvial source would now be drowned by the estuary. The periods of aeolian activity seem to have occurred in late spring and summer when the floodplain sediments were dry enough to be eroded by the wind.

Aeolian activity in the lower Derwent Valley at this time could broadly correlate with that responsible for the deposition of the Middle Unit clay dune at Crown Lagoon and the Unit 2 dune at White Lagoon. These dunes indicate a hydrologic transition from high water levels in the basins to intermittent or seasonal drying with saline conditions prevailing on the exposed lake floors. This change could have resulted in part from a decrease in precipitation, but it is more likely due to an increase in seasonal evaporation and temperatures. A climatic change of this nature, with at least partial drying of the lake basins in summer, would explain the shift toward greater slope stability and cessation of alluvial fan activity in the lower Derwent Valley.

The apparent, broad synchroneity of aeolian sand deposition in the lower Derwent area with that of clay dune formation in the Midlands is supported by the similar degree of soil profile development at these particular sites. While the pedologic characteristics of the Middle Unit clay dune at Crown Lagoon cannot be reconstructed, the nature and degree of soil development on the interstratified sandsheets at Red Gum and Lime Kiln Point and Unit 2 at White Lagoon are comparable, considering the differences in parent material. Each shows a high degree of pedological development which suggests a long period of stability and weathering. The overall soil characteristics are more consistent with a seasonally warm, subhumid climate, rather than conditions of marked aridity (Bryan and Allbritton, 1943), and the profiles could have formed during either an interglacial period or an interstadial of prolonged duration.

Pedogenesis in the lower Derwent sandsheets indicates ground-surface stability and vegetation colonization on the surface of the deposits, and probably implies both floodplain stability and a reduction in the frequency of potential sand-transporting days. Weathering of the lunette sediments occurred after the main period of lake floor exposure and deflation, and took place either before and/or during the early phase of subsequent lacustrine deposition.

Correlation of the lower alluvial fan, lacustrine and aeolian sequence in the lower Derwent Valley and Midlands with either a single or multiple cycle of major glaciation in the Highlands is as yet undetermined. As suggested in Table 15, the lower sequence could have accumulated during either a major cold stage associated with the Penultimate Glaciation, or alternatively during an early stade of the Last Glacial Stage. Similarly, the soil on the aeolian deposits could have formed during either the Last Interglacial Stage or an interstadial period of the last glaciation. Unfortunately, the local and regional evidence presently available is not sufficient to determine which hypothesis is the correct, and the solution to this problem may ultimately prove to be more complex than either of the possibilities presented here.

Preliminary evidence supporting the possibility of an early cold phase during the Last Glacial Stage includes:

1) an infinite date on periglacial solifluction material exposed at and below present sealevel at Gellibrand Point,

2) a series of infinite dates on slope debris overlying a marine beach of probable Last Interglacial age at Remarkable Cave,

and 3) an infinite date on a solifluction deposit on the upper slopes of Mt. Wellington.

As discussed earlier in Chapter 7, the lower slope deposit dated on Mt. Wellington could be equally assigned to the Penultimate Glaciation, and those at Remarkable Cave may have little or no climatic significance. However, the deposit at Gellibrand Point seems to offer supporting evidence of an early cold phase during the Last Glacial Stage. Given the close correlation between periglacial solifluction and alluvial fan activity, it is reasonable to infer from the evidence that at least limited fan deposition may have occurred during an early stadial of the Last Glacial Stage. This conclusion is partially supported by the fact that none of the fans exposed in the lower Derwent Valley are overlain by, nor do they contain, alluvial, estuarine or marine sediments deposited at a baselevel any higher than present.

The strongest argument supporting a pre-last glacial age for the lower fan deposits is the relative degree of soil development found on the overlying sandsheets and their presumed correlates in the Midlands. These profiles, while not as strongly developed as those found on the high level sediments at Old Beach and in the lower Jordan Valley, do suggest a relatively long period of exposure and weathering. As suggested earlier, the soil profiles on the interstratified deposits could have been weathered during the Last Interglacial Stage. However, there is no independent evidence to assess whether time and/or the intensity of weathering was sufficient to develop these profiles during an interstadial period. Without more data, it is not possible to further qualify the age and duration of the hiatus between the periods of alluvial fan and lacustrine deposition. However, the analytical framework of the dual hypotheses advanced throughout this study should serve as a comparative base for future research on this problem.

The first period of clay dune formation recorded from the Midlands sites was followed by a second, major phase of lacustrine sedimentation. The maintenance of high water levels was probably due to a change in climate conditions characterized by lower summer temperatures and colder winters. The Upper Unit facies at Crown Lagoon are primarily derived from slopewash and aeolian erosion, and their sedimentary and geomorphic associations suggest a reduced vegetation cover consistent with a lower temperature regime.

The abundance of reworked aeolian sand in the Upper Unit and alluvial lake sediments was probably derived from the deflation of alluvium exposed in the Birralee Valley by strong westerly winds. Deflation may have occurred seasonally or intermittently, during or following periods of increased discharge due to snowmelt runoff in the Birralee Valley.

The Zone 1 pollen assemblages support the conclusion of a reduced local vegetation cover during this period of lacustrine deposition. The adjusted sum, dominated by wind-pollinated arboreal species, some eucalypts, and relatively lower percentages of Gramineae, suggests a relatively open, herbaceous vegetation cover with few or no trees. Even assuming that the eucalypt pollen is local and not wind-transported, it seems highly unlikely that this assemblage could reflect a naturally occurring warm temperature interglacial, interstadial or Holocene vegetation community.

High lake levels in the Midlands were probably broadly synchronous with the second period of alluvial fan deposition in the lower Derwent Valley. Renewed fan activity was initiated in a colder climate with periglacial conditions on the upper slopes of the valley. A secular reduction in temperature, necessary for the large scale production of solifluction debris, would effectively limit the vegetation cover and again result in widespread slope instability and fan deposition. Seasonal snowmelt probably provided most, if not all, of the water responsible for episodic fan deposition in the lower parts of the tributary valleys.

As yet radiocarbon control is not available for this period of alluvial fan activity in the lower Derwent Valley, but a last glacial age seems likely. Radiocarbon dates between 24-33,000 BP from the Rocky Cape fan probably indicate part of the time range for the second generation of alluvial fans in the lower Derwent area. The Rocky Cape dates are somewhat earlier than, but roughly correspond with a date from a site at Henty Bridge which indicates that the maximum of the Last Glacial Stage occurred after 23,640 BP (GaK-5597) (Colhoun, pers. comm.). Thus, it appears likely that most of the Derwent fans were deposited before, during or immediately following the last glacial maximum in Tasmania.

The magnitude of climatic change in Tasmania during the last glacial maximum is imperfectly known. Derbyshire (1971) suggested that the atmospheric circulation at this time was characterized by a relatively high frequency of cyclonic disturbances. These conditions, reflecting an intensification of the overall westerly air circulation, are believed to have resulted from a northward shift of the Antarctic Convergence Zone with the presence of a semipermanent high pressure cell over the Australian continent. In theory, an increase in the frequency of cyclonic storms during the glacial maximum would result in a windy and predominantly cold climate in southeastern Tasmania with most, if not all, of the winter precipitation falling as snow.

Galloway (1965a) postulated a 5° C reduction in annual temperature in Tasmania for the Last Glacial Stage on the basis of the assumed lower limit of periglacial solifluction of 600 m. Derbyshire (1973) suggested a 6.5° C temperature reduction based on the limits of rock glacier formation in the western Highlands. Bowden (1974), from local evidence in the Tyndall Mountains of Western Tasmania, indicated that the minimum snowline elevation was at about 610 m during the last glacial maximum. Using this figure and average lapse rates and other meteorological data from Queenstown, Bowden calculated a mean annual temperature reduction of about 10° C during this time.

These values, while approximations based on numerous assumptions, give an idea of the possible magnitude of temperature reduction in the lower Derwent Valley and Midlands during the maximum of the last glaciation. Using Bowden's figure as a rough maximum value, the mean annual temperature during the last glacial maximum would have been in the order of 0° C at Oatlands and 2° C at Hobart. Temperature ranges on the upper slopes of the Derwent Valley would have been several degrees lower than that of Hobart, insuring a significant reduction in the number of frost-free days and favoring the large scale production of solifluction debris.

Local environmental differences probably existed between the Midlands and lower Derwent regions, especially in terms of the annual temperature range. Superimposed on the secular reduction in temperature, the Midlands probably had a more continental climate due to the increased land mass of the island created by the glacio-eustatic lowering of sealevel. The climate of Midlands would have been colder and possibly more arid than the lower Derwent due to the effects of katabatic winds from the ice cap situated on the Central Plateau to the northwest.

The second, major phase of aeolian activity, resulting in the deposition of the basal sandsheets at Glenfield, Old Beach and Bridgewater (as well as those overlying many of the alluvial fans), was broadly synchronous with the final period of slope instability and fan accumulation. The date of 15,740 BP from the dune at Malcolms Hut in the Coal River Valley provides a general age for part of the period of aeolian activity. However, the exact age of the lower Derwent sandsheets is unknown and can only be approximated as sometime during the later part of the Last Glacial Stage. Aeolian activity could have occurred throughout this period, either during alluvial fan deposition and/or immediately following the main phase of slope instability.

The geographic factors which influenced and limited the distribution of aeolian sheets in the lower Derwent area are most likely related to the position of exposed meander loops in the former channel or to local sites of alluvial fan deposition. The original floodplain deflation areas are now drowned by the sea and probably buried by later estuarine sediments. The low relief of the dunes does suggest specific, point sources along the emerged river valley and most of the sandsheets were deposited as climbing cliff-top dunes by high intensity, westerly winds.

The deflation of channel and/or alluvial material from the Derwent could have occurred seasonally or at least intermittently, either during and/or following periods of peak river discharge and overbank deposition. Large amounts of runoff, probably enhanced by seasonal snowmelt, may have concentrated large volumes of debris in the river and the Derwent is likely to have been a high energy, fluvial system with a braided series of anastomosing channels. The periods of deflation most likely occurred during the late spring and summer months when the floodplains were dry enough to allow deflation to occur.

The evidence available indicates that this phase of widespread aeolian activity occurred toward the end of the Last Glacial Stage. The dunes were most likely formed under a cold, windy and at least seasonally dry climate. The wide variety of aeolian dunes and sheets formed at this time closely reflects both the specific location of the depositional site and the availability of the source material, whether alluvial or lacustrine. The sandsheets of the lower Derwent Valley were deflated from channel and/or floodplain material exposed in the emerged Derwent River, while the predominantly sandy lunette deposits of the Midlands sites resulted primarily from the deflation of actively accumulating beach materials.

The stone implements near the base of the Old Beach sandsheet provide the earliest evidence of Aboriginal occupation from either area. Their basal stratigraphic position indicates that the phase of occupation was coeval with the initial formation of the dune. The exact age of occupation cannot be precisely determined, but the sandsheet was deposited before the sea flooded this portion of the estuary some 9-11,000 years ago. This relationship indicates that Aboriginal Man was present in southeastern Tasmania by at least the later part of the Last Glacial Stage; a conclusion supported by the date of 18,550 BP for occupation on Hunter Island off the northwest coast (Bowdler, 1974a). Aboriginal occupation during this part of the last glaciation corroborates earlier deductions by Jones (1968) concerning the probability of human migrations from the mainland over the Bass Strait corridor during glacio-eustatic low sealevels.

The very limited archeological material from Old Beach suggests hunting activities, and the site was most likely occupied by a small number of individuals during intermittent or seasonal migration from coastal areas now drowned by the sea. The geomorphic and stratigraphic relations suggest that a cold, windy environment prevailed during the occupation phase at the Old Beach site. The colder interior areas of the island may or may not have been occupied permanently at this time, but the main areas of Aboriginal occupation were more likely to have been concentrated along the more temperate coastline. The ecological adaptations of this population, based on fragmentary evidence from this site and at Hunter Island, may have been broadly similar to those of the Amerinds of Tierra del Fuego in Argentina and with other groups occupying similar environments in the Northern Hemisphere.

The broad synchroneity of sandsheet deposition in the lower Derwent area with that of sand lunette formation in the Midlands lacustrine sites is further supported by the relatively similar degree of soil profile development on these particular units. These soils are less strongly developed than are those on the older aeolian sediments, but are more strongly altered than the sands of known Holocene age.

The soil profile on the Upper Unit lunette at Crown Lagoon is essentially similar to that formed on the Bridgewater sandsheet, and to a lesser extent, those on the Glenfield and Old Beach equivalents. This comparison, based on relative profile development, does support a roughly similar intensity and/or duration of weathering at the four sites. The minor profile variations observed in the lower Derwent sandsheets are most likely due to inherent variations in parent material, rather than significant differences in duration and/or intensity of weathering over time.

Weathering of the sandsheets and lunette dunes implies ground-surface stability at both the depositional sites and the deflation source areas. At Crown Lagoon, pedogenic alteration of the Upper Unit lunette sands occurred during and following drying of the lake. The period of low water levels recorded from the Zone 2 pollen assemblage, resulted from increased evaporation rates, rather than a reduction in precipitation. The hydrologic transition to an intermittent or seasonal marsh most likely occurred during a climatic shift to warmer conditions, especially during the summer months. The Zone 2 pollen assemblage is fully consistent with this interpretation and suggests the establishment and maintenance of a closed grassland, at least in the area around the lake. The extremely low abundance of Myrtaceae pollen in this assemblage, almost at background levels, strongly implies a landscape nearly devoid of eucalypts and sclerophyll shrubs. Environmental factors limiting eucalypt growth and propagation during this period were most likely due to high frost frequencies. The present distribution of *E. pauciflora*, the frost resistant, nonendemic eucalypt species in the Midlands, is probably a relic inherited from the cold climatic conditions that prevailed during much of the Last Glacial Stage.

Deposition of the upper aeolian clay member at White Lagoon (Unit 4) occurred during the same period of lake desiccation. The date of 9,550 BP from Lake Tiberias in the Midlands provides a minimum age for this period of clay dune formation, and can be used to establish a tentative upper time limit for similar sequences in other areas of the Midlands and southeastern Tasmania. However, the local evidence suggests that clay dune formation need not occur at every lake basin, even though lake desiccation seems to have been relatively widespread. The primary factors, other than climate, which seem to have influenced clay dune formation include the size of the lake basin, size of the drainage area, and the availability of effluents in the catchments.

The orientation of the lunettes in the Midlands indicate that the aeolian sequences were deposited under the influence of relatively strong northwesterly winds. Since winds from this direction today are related mainly to anticyclonic air circulation over the mainland in summer, it is likely that the lunettes formed under similar conditions in the past, although wind velocities may have been stronger. The more westerly orientation of the lower Derwent sandsheets does not necessarily indicate a different paleowind regime during aeolian activity since northwesterly winds in summer are channeled down the east-west trending valley.

Warmer summer temperatures, effecting increased evaporation in the Midlands, would almost certainly be paralleled by a significant reduction in the extent of frost weathering on the upper slopes of the lower Derwent Valley. The alluvial fans may have been mostly inactive by this time due to increased vegetation cover and slope stability at higher elevations. The inferred change in local environmental and related geomorphic processes is associated with a general climatic amelioration beginning at the end of the Last Glacial Stage and continuing throughout the Holocene. The climate at this time probably changed from being continental with cold winters and warm summers to slightly more temperate with cooler winters and warm summers, and more precipitation. Warmer temperatures with increased humidity is also suggested from the types of soils developed across nearly all of the aeolian and slope deposits exposed at the present groundsurface.

Peterson (1968) and Macphail and Peterson (1975) have published several dates for the period of deglaciation in western Tasmania. The oldest of these is a date of 11,530 ± 240 BP (I-7683) from the cirque at Lake Vera (elev. 560 m) in the Frenchmans Cap area, and the youngest is 8,280 ± 460 BP (GaK-1990) from James Tarn (elev. 1,158 m) at Mt. Field. However, these determinations are only local minimum ages and terminal deglaciation may have occurred somewhat earlier.

Weathering of the aeolian sandsheets and lunette dunes appears to have taken place throughout the period of deglaciation in the Highlands and continued into the Holocene until local profile truncation occurred through Aboriginal, and in some cases, European landscape modification. A relatively long period of soil formation at these sites is indicated as the profiles are too strongly developed to have formed during a relatively short weathering episode. The lower Derwent profiles of this general age contain more free iron oxide and show an overall higher percentage of clay in their B horizons than does the Upper Unit lunette profile at Crown Lagoon. Regional differences in weathering are most likely due to the generally higher proportion of dolerite and basalt-derived fines contained in many of the lower Derwent sandsheets and dunes. In addition, local environmental conditions may have been more suitable for relatively stronger chemical weathering in the lower Derwent area because of greater humidity and the moderating effect of the sea during and following the Holocene marine transgression.

Holocene Sequence - The Zone 3 pollen assemblage from Crown Lagoon approximates the beginning of the Holocene at this site and suggests a continued climatic amelioration into recent times. The exact age of the assemblage is unknown, but the pollen indicates a sclerophyll woodland with floristic and structural characteristics very similar to that of the modern vegetation community. Eucalypt expansion at this time is most likely related to a decrease in the frequency of heavy frosts and probably to a slight increase in annual precipitation. Both lake basins, and many others in the Midlands, were probably occupied by seasonal or intermittent marshes throughout the Holocene.

The local radiocarbon and archeological evidence from the Holocene coversands suggest that Aboriginal Man was an important geomorphic agent in modifying the pre-existing aeolian landforms through site-intensive occupation. The intentional or accidental use of fire undoubtedly played a major role in altering the nature and effectiveness of vegetation over large areas of the island (Jones, 1968; Goede, 1973). On the local level, concentrated human activity modified the former aeolian deposits to the extent of creating new landforms, independent of climatic conditions favoring stability.

The lower unit of the coversand sequences found at Old Beach and Glenfield in the lower Derwent, and on the lunette at Crown Lagoon formed through the disturbance of the underlying sediments by the activities of Aboriginal Man. The accumulation of these deposits is related to the aeolian redistribution by westerly winds of the A horizons formed in the older weathering profiles. Burning of the local sites, and other activities favorable to altering the natural structure and density of the vegetation was significant in contributing to groundsurface instability.

These surface coversand units have no particular climatic significance, but rather result from cultural impact on the landscape. The activities of Aboriginal Man may have coincided with a supposed Holocene arid phase (Davies, 1967, 1973), but these deposits cannot be used as the only evidence to support regional aridity, if it occurred. In addition, Unit 2 at Glenfield was deposited several thousand years after the postulated mid-Holocene arid period. The most significant feature characterizing these types of landforms is that their formation can occur at any time within the range of human occupation, and multiple deposits of different age can accumulate on a site quite independent of climatic controls that would favor aridity. The only environmental conditions necessary for their accumulation are an easily eroded groundsurface, wind velocities above the critical velocity threshold for the particular sediment, and the presence of Man as the geomorphic agent initiating change.

The Holocene occupation of the lower Derwent Valley appears to have been established at least by 5,800 BP, and the local archeological evidence suggests an economy based on both hunting and gathering and shellfish resources. The distribution of shell middens and other archeological sites in the valley indicates that the greatest density of Aboriginal population was apparently along the margins of the estuary. Kroeber (1939) reported that the Indians of California maintained nearly twice the population density along the coasts as they did in inland areas and this model seems to apply to the lower Derwent Valley. The occupation of the Glenfield site, although intensive, may have been peripheral to the main habitation area of the lower Derwent.

Crown Lagoon could have been occupied during seasonal migrations from the coast to inland areas as suggested by Lourandos (1970). Population pressure may have become more intense as the ameliorating Holocene climate allowed for more extensive and permanent occupation of the Midlands. The Aboriginals who occupied this site between 4,800 to 4,200 BP were primarily engaged in hunting and gathering activities, and the marshy lagoon probably concentrated game animals around the site.

The formation of the secondary cover sands at each site was followed by stability and weak pedogenesis, probably initiated by site abandonment. The similar degree of oxidation in the coversands reflects not only the same intensity of weathering in both areas, but also the depleted nature of the original parent material, regardless of time of formation.

Weathering was followed by local reoccupation of the sites as shown by the thin, organic fine sand wedge at Glenfield and Crown Lagoon. At Glenfield occupation occurred either immediately before or during the initial period of European settlement. Truncation of the coversand units with extensive disturbance of the sandsheets has continued throughout the period of European settlement. The generation of tertiary aeolian deposits at these sites by European land use has occurred in a manner similar to the disturbance caused by the Aboriginals, but at a much accelerated rate.

Comparisons with Southeastern Australia - It is not yet possible to establish firm correlations of the late Quaternary sequences recorded in this dissertation with those previously studied in southeastern Australia. The lack of precision in a regional correlation is primarily due to the relatively incomplete radiocarbon chronology for most of the major depositional events in the lower Derwent and Midland sequences. In addition, the absence of stratigraphic detail and too few age determinations of specific events in many of the mainland sequences has led to continued debate on the nature of climatic change, geomorphic histories and the synchroneity of events over wide areas during the late Quaternary period (Bowler, 1967; Galloway, 1971). With these limitations in mind, Table 16 presents an overview of selected late Quaternary sequences from the mainland and suggests exceedingly tentative comparisons with the results of this study. The mainland sequences are reviewed in Chapter 1 along with other relevant studies, and were chosen because they had some geomorphic similarities to the lower Derwent and Midlands sequences and because their stratigraphy was partially controlled by radiocarbon chronologies.

In general, the data of this table not only suggest a very broad framework of correlation with the events recorded in the lower Derwent and Midlands sites, but also of those across southeastern Australia. The apparent synchroneity of high lake levels near the maximum of the Last Glacial Stage is especially significant as these sequences closely correspond with glacial conditions in the Snowy Mountains as reported by

TABLE 16

A COMPARISON OF SELECTED LATE QUATERNARY SEQUENCES FROM THE AUSTRALIAN MAINLAND AND SOUTHEASTERN TASMANIA

CHRONOLOGY	EPOCH	WILLANDRA RIVER SYSTEM BOWLER, 1971; 1973	GOULBURN VALLEY BOWLER, 1967	LAKE GEORGE GALLOWAY, 1965 a,b 1967	LAKE KEILAMBETE BOWLER & HAMADA, 1971	SOUTHEASTERN TASMANIA SIGLEO, THIS DISSERTATION
10	HOLOCENE	Lake Levels Variable	(Soil) Source-bordering Dunes	Lake Levels Variable	Lake Levels Variable	Low Lake Level (Soil)
Radiometric age in thousands of years before 1950 20 30 40 50	PLEISTOCENE	(Soil) Lunette Clay Dune Low Lake Level Lunette Sands (Zanci) High Lake Level (Soil) Lunette Clay Dune Low Lake Level Lunette Sands Aboriginal Occupation (Mungo) High Lake Level	Source-bordering Dunes (Soil) Source-bordering Dunes (parna)?	(Soil) 13 m Shoreline High Lake Level Alluvial Fans Solifluction (?)	(Soil) Low Lake Level High Lake Level	Lunette Clay Dunes Low Lake Levels Source-bordering Sandsheets Aboriginal Occupation Lunette Sands High Lake Levels Alluvial Fans Solifluction (?)
		ABSOLUTE AGE UNCERTAIN				
		(Soil) Lunette Clay Dune Low Lake Level Lunette Sands (Golgol) High Lake Level		(Soil) 30 m Shoreline High Lake Level Alluvial Fans Solifluction (?)		(Soil) Lunette Clay Dune Low Lake Level Source-bordering Sandsheets Alluvial Fans High Lake Level Solifluction

Galloway (1965) and Costin (1971). Both Bowler and Galloway have suggested that the high lake levels, which occurred in many areas during this period, are related to a lower temperature regime and much reduced evaporation rates; an interpretation contrary to the simple glacio-pluvial relationship advanced by Dury (1967; 1973) and others. The broad synchroneity of late glacial warming is also apparent from these sequences, and Bowler has indicated that this period of lake desiccation resulted primarily from rising temperatures, especially during summer.

A review of Bowler's study on lunette lakes in the Willandra River system shows three major lacustrine oscillations during the late Quaternary period; the oldest of which lies outside the range of radiocarbon dating. Bowler suggests that each high lake stage, accompanied by sand lunette deposition, occurred during a cooler temperature regime with reduced summer evaporation rates. This interpretation, based on sedimentary and geochemical relations, is fully consistent with the Zone 1 pollen assemblage from Crown Lagoon. These independent conclusions, along with the age relations of Bowler's upper two high lake stands and the evidence from Lake Keilambete, tend to support Galloway's contention that the 13 m Lake George shoreline indicates relatively cold, windy and possibly drier conditions during the maximum of the Last Glacial Stage. Relatively arid conditions during this period, characterized by an open eucalypt woodland, are also reported by Dodson (1975) and Martin (1973) from pollen sequences at Lake Leake, South Australia and the Nullabor Plain, respectively.

Without detailed radiocarbon control on the cycles of lake fluctuations in the Midlands and aeolian deposition in the lower Derwent area, it is difficult to make more detailed correlations with either the

Willandra sequence or that from Lake George. The Upper Unit high lake stage and its sand lunette member could equate with either the Mungo (25-40,000 BP) or Zanci (17-23,000 BP) high lake stages; or both. The last period of alluvial fan deposition in the lower Derwent area and elsewhere in the lowlands of Tasmania could correlate broadly with the final period of alluvial fan activity around the margins of Lake George. The interpretation that alluvial fan activity in the lower Derwent coincided with high lake levels in the Midlands is supported by Galloway's evidence, which suggests that only a short interval, if any, separated the periods of fan activity from the times of high lake levels at Lake George.

If broad correlation of these deposits with the maximum of the Last Glacial Stage is viable as seems likely, then the Unit 4 clay dune in the White Lagoon lunette is probably broadly equivalent with the Zanci clay dune and others deposited on the mainland between 13-17,000 BP. As stated earlier, Bowler suggested that the periods of clay dune formation were related to a combination of high summer temperatures and cold, dry winters. His conclusions pertaining to the environmental conditions influencing clay dune genesis are consistent with the Zone 2 pollen evidence from Crown Lagoon, particularly with reference to increased frost frequencies and greater soil moisture deficits during this period.

In the Goulburn Valley, Bowler has reported that source-bordering sand dunes were extensively developed along streams and are dated at 20,000, 16,000 and 13,000 BP. Although Bowler cautions that the presence of these dunes does not necessarily imply glacial aridity, he does suggest that the periods of aeolian activity were associated with the following conditions: 1) an abundance of sand on the channel point bars; 2) seasonal drying and exposure of the floodplains to prevailing west to southwesterly winds; and 3) the relative absence of vegetation, especially trees, along these streams during glacial and late glacial times.

The date of 15,740 BP on aeolian deposition at Malcolms Hut is significant in relation to those from the Goulburn Valley dunes, and the sequences from both areas suggests the general validity of a broad regional correlation for this period of instability and aeolian erosion. The source-bordering sandsheets at Glenfield, Old Beach and Bridgewater were probably deposited near the end of the maximum of the Last Glacial Stage. The formation of these dunes also required at least seasonal aridity with floodplain and vegetation conditions similar to those proposed by Bowler in the Goulburn Valley. It is not possible to assign all of the later dunes and sandsheets in southeastern Tasmania to a distinct time range, such as either glacial or late glacial, as local aeolian activity probably occurred throughout the later part of the Last Glacial Stage.

The correlation of the older sequences recorded in this study with those from the Willandra system or Lake George is feasible, but highly speculative given the absence of radiocarbon control on any of the relevant events. As the Middle Unit deposits at Crown Lagoon and their inferred equivalents at White Lagoon almost certainly lie outside the range of radiocarbon dating, it is possible that these units correlate with the similar Golgol sequence in which the older high lake stage was followed by clay dune formation. The type of soil formation observed on the Unit 2 clay dune at White Lagoon and the lower sandsheets in the Derwent area cannot be directly compared with that reported on the

Golgol dune, but each profile is strongly developed and probably formed over a considerable period of time.

Similarly, the older slope and alluvial fan deposits in the lower Derwent area may correlate with the lower fan and solifluction (?) deposits at Lake George as reported by Galloway. The apparent cyclic repetition of the fan sequences in both areas, each apparently associated with periglacial conditions in the Highlands, lends further support to the broad synchroneity of late Quaternary events between Tasmania and the Australian mainland. However, all that can be said about the older deposits at present is that they lie outside the range of radiocarbon dating and most likely equate with either two cold stades of one glacial stage or perhaps with two distinct glacial stages.

The major periods of stability and soil formation recorded in the lower Derwent and Midlands successions may be broadly synchronous with those described from mainland studies (Mulcahy and Churchward, 1973); however, inherent difficulties are evident in correlating soil-stratigraphic units over vastly different geographic regions (Bowler, 1967). Nearly all mainland studies have reported some kind of pedogenesis on deposits of last glacial or late glacial age. Although soil formation probably occurred at different times and with different intensity throughout the later part of the Last Glacial Stage, it is likely that the profiles reflect the general stability which occurred at the end of the Last Glacial Stage and continued through most of the Holocene. The profiles formed on the sandsheets and dunes in southeastern Tasmania during this period are related to the same regional trend toward groundsurface stability due to increased vegetation cover. The older soils developed on the alluvial deposits in the lower Derwent Valley considered to be of Last Interglacial age could correlate with apparently similar sequences known from coastal areas of the mainland, but sufficient stratigraphic and pedologic detail is not available to provide definitive comparisons of this nature.

The archeological evidence near the base of the Old Beach sandsheet clearly indicates a glacial age for Aboriginal Man in southeastern Tasmania. Since the Bass Strait corridor was exposed during the last glacio-eustatic lowering of sealevel in the Pleistocene (Jennings, 1959a; 1971) the antiquity of Man in Tasmania is potentially as old as that of southeastern Australia, currently dated to about 32,000 BP (Bowler, et. al., 1970). Since the artifacts at Old Beach were discovered during the course of routine geomorphic investigations, it is highly likely that some other, and probably older archeological sites, will be found with future research on the nature of the late Quaternary sandsheets and dunes in Tasmania.

The anthropogenic origin of the Holocene coversand units in the lower Derwent area and at Crown Lagoon is a phenomenon apparently not reported from any of the mainland sequences and the climatic significance of similar, locally occurring deposits must be questioned in the future. The importance of these deposits cannot be underestimated because their presence and distribution provide valuable insights on the effects of Man as a geomorphic agent of change. In this regard, there is no evidence in either the lower Derwent area or Midlands of a mid-Holocene "Climatic Optimum" of sufficient intensity and/or duration to permit aeolian erosion to occur, independent of the activities of Aboriginal Man and his effect on the landscape.

This conclusion is contrary to the earlier statements by Davies (1967) in Tasmania and numerous other authors working on the mainland. The Zone 3 pollen assemblage indicates continued low water levels throughout the Holocene, but never complete drying of the lake. The pollen evidence from the studies of both Dodson and Martin is also contrary to the existence of a mid-Holocene arid period as proposed by Crocker (1946) and Crocker and Wood (1947) in South Australia. Dodson presents evidence suggesting that the period between 4,000 and 6,000 BP was wetter than present, and Martin indicates that Aboriginal land use was responsible for a reduction in vegetation during the mid-Holocene.

In summary, the evidence presented in this dissertation suggests that the general pattern of late Quaternary climatic change in Tasmania was broadly similar to that interpreted from many of the mainland sequences. A detailed radiocarbon chronology is needed to conclusively demonstrate the degree of synchroneity of the events. The major events in Tasmania may have been slightly diachronous with those in southeastern Australia due to both latitude and the effects of oceanic influences on the environment, but the direction of climatic change and its effect on geomorphic processes was similar.

CHAPTER 12

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this dissertation was to investigate the origins of selected inland sandsheets and lunettes in southeastern Tasmania, and to evaluate their significance in terms of both climatic change and their history as human occupation sites. Since the study is a paleoenvironmental reconstruction, an interdisciplinary methodology was used to synthesize diverse evidence and place a broader geographical perspective on the problem. The approach was geomorphic in the sense of analyzing landform evolution; but palynologic, stratigraphic and pedologic data were used to demonstrate spatial and temporal relationships between climatic change, landforms and vegetation. This chapter briefly presents the main conclusions and recommends several areas of future research in related topics.

Conclusions - Significant and repeated environmental changes have occurred in southeastern Tasmania during the late Quaternary period. These changes are of local significance, but their general trend reflects the worldwide pattern of climatic changes which occurred during this period. Evidence for late Quaternary climatic change is well documented in many other regions of the world, but not for these latitudes of the Southern Hemisphere. The record of geomorphic processes and depositional forms in the lower Derwent Valley and Midlands is thought to have resulted primarily from changes in temperature, and secondly from changes in precipitation, with their combined effects on evaporation, vegetation and landscape stability. The main conclusions include the following:

1) High level alluvial and estuarine sediments were deposited up to 15 m above present sealevel in the lower Jordan Valley, and at Bridgewater and Old Beach on the Derwent River. These deposits are thought to have accumulated during a positive sealevel transgression of the Last Interglacial Stage, and they are correlated with other similar deposits along the coast of southeastern Tasmania believed to be of this general age. The high level sediments examined in this study are strongly weathered, and soil development apparently took place over a long period in a climate similar to the present before profile truncation occurred.

2) The evidence presently available indicates that the late Quaternary period in southeastern Tasmania was characterized by at least two major cold phases of sufficient magnitude and/or duration to initiate widespread periglacial and alluvial fan activity in the Derwent Valley, and to maintain seasonally high lake levels in the Midlands. These cold phases, tentatively correlated with one or more major ice accumulation stages in the Highlands, significantly lowered temperatures across the unglaciated lowlands, especially in summer. Annual precipitation, particularly in the Midlands, may have been reduced due to an accentuation of the rainshadow effect during and following glacio-eustatic lowerings of sealevel. The climatic deteriorations caused a marked reduction in vegetation cover and probably a significant lowering of the tree line. Periglacial debris on the upper slopes of the Derwent Valley was reworked by snowmelt and redeposited in fans of alluvial material graded well below present sealevel. Simultaneously, reduced summer temperatures and evaporation rates sustained high lake levels in the Midlands and caused the deposition of lacustrine sediments.

3) Each cold stage was followed by an interval when widespread aeolian activity formed sandsheets in the lower Derwent Valley and clay lunette dunes in the Midlands. Sandsheet deposition began near the end of each cold phase and was related to marked seasonal aridity, strong west to northwesterly winds and local floodplain instability. Lunette formation probably occurred synchronously and was initiated by intermittent drying of the lake basins in a climate when summers were warmer than before with attendant higher evaporation rates. Strong winds may have been prevalent throughout the year, but the evidence indicates that aeolian erosion was most significant during the late spring and summer.

4) Each of the two phases of aeolian activity was followed by groundsurface stability and weathering in a climate similar to the present. Warmer temperatures during these periods resulted in an increased vegetation cover, catchment stability, and the end of periglacial, alluvial fan and lacustrine deposition. The paleosols formed on the older sandsheets and lunettes are similar, suggesting both the contemporaneity and similar intensity of weathering during this particular period of soil formation. The relative stratigraphic position of these paleosols indicate that they may have been of interglacial or interstadial status. Similarly, the soils formed on the younger sequence of sandsheets and lunettes all indicate nearly the same intensity of weathering during the most recent period of general stability, at the end of the Last Glacial Stage and Holocene.

5) The age of the older sequence of alluvial fan, lacustrine and aeolian deposits is uncertain, and the succession could correlate with either two cold stades of a single glacial cycle or with a double cycle of major glaciation in the Highlands. In the first instance, the older

deposits could date from an early cold stade of the Last Glacial Stage with stability and weathering during an interstadial. In the second, the sequence could have accumulated during the Penultimate Glaciation. If this hypothesis is correct, then weathering most likely occurred during the Last Interglacial Stage. However, there is local evidence at Gellibrand Point on the South Arm Peninsula to suggest that a phase of periglacial activity probably occurred during the early part of the Last Glacial Stage. The regional implications of this cold stade are not fully understood, but the first period of alluvial fan and sandsheet deposition in the Valley could have taken place at this time. If this hypothesis is correct, then weathering of the lower sandsheets and dunes most likely occurred during a Last Glacial interstadial period.

6) <u>During the later part of the Last Glacial Stage (at or near the maximum) renewed cold climate conditions caused widespread periglacial activity on the upper slopes of the Derwent Valley and alluvial fan deposition in the lower tributaries, and cooler summer temperatures and lower evaporation rates maintained high lake levels in the Midlands</u>. Winters were much colder than present with much of the precipitation occurring as snow. The Zone 1 pollen assemblage from the Upper Unit high lake sediment at Crown Lagoon indicates a landscape nearly devoid of trees throughout most of this cold phase with the vegetation approaching an open grassland or steppe. The aeolian sand members of the lunettes were deposited at this time, being deflated by strong west to northwesterly winds from actively accumulating beaches.

7) The final episode of periglacial alluvial fan and lacustrine deposition was closely followed by the second major phase of aeolian activity during which the younger sequence of sandsheets, dunes, and lunettes were formed. The date of 15,740 BP from the dune at Malcolms Hut provides a minimum age for this interval of widespread aeolian activity. The sandsheets at Glenfield, Old Beach and Bridgewater were deposited about this time, shortly after the maximum of the Last Glacial Stage. The widespread occurrence of other sandsheets and dunes in southeastern Tasmania reflect the regional extent of aeolian activity at this time.

8) The climate during the later part of the Last Glacial Stage was characterized by warmer summers than before, but winters remained cold. Warmer summers and higher evaporation rates were primarily responsible for intermittent drying of the Midlands lake basins with local clay dune formation. The Zone 2 pollen assemblage from Crown Lagoon indicates that the open grassland or steppe vegetation of the main cold phase was replaced by a more dense grassland in late glacial times. Relatively few trees, especially eucalypts, were present in this part of the Midlands and the major factor limiting tree growth and propagation appears to have been high frost frequencies. The present distribution of the non-endemic snowgum, *E. pauciflora*, is a relic inherited from the cold conditions which prevailed during the Last Glacial Stage.

9) The lithic artifacts near the base of the Old Beach sandsheet indicate a glacial age for Aboriginal Man in southeastern Tasmania. Given the opportunities for migrations across the exposed Bass Strait corridor during Pleistocene low sealevels, the antiquity of human occupation in Tasmania is potentially as old as that of adjacent parts of the mainland.

10) General stability followed the aeolian activity in south-eastern Tasmania with soil development on the sandsheets, dunes and lunettes. Weathering was due to an amelioration of climate in the early Holocene period, with perhaps the most significant changes being increased temperatures and precipitation. These changes would be accentuated by the increased insularity caused by the Holocene marine transgression. The Zone 3 pollen assemblage from Crown Lagoon indicates the replacement of the closed grassland by sclerophyll woodland and the establishment of an essentially modern vegetation community during the Holocene.

11) Stability and weathering of the aeolian deposits continued in the Holocene until local profile truncation occurred through the activities of Aboriginal Man. The lower coversand units at the lower Derwent sites and at Crown Lagoon were formed as the Aboriginals occupied these sites and cannot be used as evidence to support regional aridity during the Holocene. In fact, there is no independent evidence from either the lower Derwent Valley or the Midlands to prove a supposed mid-Holocene arid period in south-eastern Tasmania. The coversand units have no particular climatic significance and their formation can occur anytime within the range of human occupation. The only environmental conditions necessary for their formation are an easily eroded groundsurface, strong winds and the site-intensive activities of Man as the geomorphic agent initiating change.

12) Comparison of the evidence in this study with that from several mainland sequences suggests the strong probability of a regional correlation of major events during the late Quaternary period. Much more research is necessary, both in Tasmania and the mainland, to conclusively demonstrate the synchroneity of events and to elucidate the complete pattern of changes.

Recommendations - This dissertation sheds some light on several of the more important questions concerning the origins and environmental significance of the inland aeolian deposits found in southeastern Tasmania. However, some questions remain unanswered and new ones have been raised about the late Quaternary history in this part of southern Australia. Future research directed toward the resolution of some of these problems could include:

1) A detailed regional study of the periglacial and alluvial fan deposits in the unglaciated lowlands of Tasmania. Special attention should be directed to the spatial and temporal relationships of climatic change which have influenced the deposition of these sediments.

2) An integrated geomorphic-palynologic study of the sediments contained in the larger lake basins of the Midlands and southeastern Tasmania. An initial goal would be to establish, as closely as possible, the relationship between the regional "pollen rain" and the modern vegetation communities. Changes in vegetation through time, as well as inferences about climate change, could then be reconstructed from the fossil pollen record with much greater detail than was possible in this study. The advantage of combining pollen research with geomorphic studies lies in relating specific depositional events, such as lunette formation, with changes in vegetation and thus climate through time.

3) A comprehensive study of the high level alluvial, estuarine and marine sediments distributed around the coast of Tasmania. In addition to providing information on sealevel changes, the study could provide a relative time base by which to correlate other sequences. In some areas, such as the lower Derwent Valley, the identification and interpretation of

the high level sediments may be the best means of separating the sequences which come before from those that follow the transgression. Thus, the time-stratigraphic position of the lower sequence of aeolian and alluvial fan deposits may be more precisely determined through studies of this nature.

4) Finally, additional research is needed to provide a more regional overview of the periods of aeolian activity and their relationships with glacial events in the Highlands. These studies, if supplemented with a radiocarbon chronology, would provide a basis for more accurate correlation of the aeolian sequences; provide more detailed information on the local environments of deposition; and add precision in regional correlations with similar mainland sequences. Such research could also potentially result in the discovery of older archeological sites; thereby providing greater detail on the ecological adaptations of Aboriginal Man in Tasmania during the Last Glacial Stage.

APPENDIX 1

PRE-QUATERNARY GEOLOGY OF THE LOWER DERWENT VALLEY

PRE-QUATERNARY GEOLOGY OF THE LOWER DERWENT VALLEY

(Geol. Surv. Tasm., 1972)

ERA	PERIOD	STRATIGRAPHIC UNIT	DESCRIPTION	MAXIMUM THICKNESS (m)
			SEDIMENTARY ROCKS	
Cenozoic	Tertiary		Post-basalt gravel Sub-basalt tuff Predominantly sub-basalt silt and fine sand with lignite	100 +
			unconformity	
Mesozoic	Triassic	"Feldspathic" Sandstone	- Undiff. Upper Triassic lithic arkose and lutite with coal measures	
			- Predominantly massive quartz mudstone; minor quartz sandstone with beds of lithic sandstone coal	100 +
		Knocklofty Formation	- Medium to fine quartz sandstone, minor mudstone. Much mica and graphite	
			- Medium to coarse quartz sandstone with minor mudstone; clay pellet beds	200 +
			- Thickly bedded, medium to coarse quartz sandstone with very minor black shale	
			disconformity	
Paleozoic	Permian	Cygnet Coal Measures	- Including quartz arkose, carbonaceous mudstone with carbonaceous fragments	20 +
		Ferntree Group	- Unfossiliferous quarts siltstone, including Risdon Sandstone at base	200
		Malbina Formation	- Quartz sandstone and siltstone; fossiliferous in upper and lower members	100
		Cascades Group	- Fossiliferous beds of dominantly mudstone and siltstone with Berriedale Limestone	210 +
		Faulkner Group	- Conglomerate, sandstone, mudstone and shale. Occasionally fossiliferous	40
		Bundella Formation	- Fossiliferous sometimes calcareous mudstone	60
		Undiff/Lower Permian	- Predominantly unfossiliferous quartz mudstone	150 +
			IGNEOUS ROCKS	
Cenozoic	Tertiary	Brighton Basalt	Predominantly olivine basalt and ranges from scoriaceous to vesicular and massive. Usually extremely fine grained, but porphyritic, to locally course grained with a dolerite texture. Contains several persent iron ore	50 +
Mesozoic	Jurassic		Tholeiitic quartz dolerite of medium to fine grained texture. Iron ore in form of illmenite and magnetite	450 +

APPENDIX 2

POLLEN FREQUENCIES FROM CROWN LAGOON

(Adjusted sum shown in parenteses)

Sample No.	*Eucalyptus* (*Myrtaceae*)	*Acacia*	*Banksia*	*Casuarina*	*Phyllocladus*	*Pinus*	*Picea*	*Pherosphaera*	Cupressaceae	*Nothofagus*	*Podocarpus*	Gramineae	*Pomaderris*	*Bursaria*	Caryophyllaceae
Surface	20.0	0.5	0.5	0.5	1.0	0.5			0.5			46.5		0.5	
Pond	13.0 (30.5)			(1.0)			0.5		0.5 (1.0)			18.5 (26.0)			
10-15 cm	11.5 (16.0)			1.0 (1.5)	1.5 (2.5)			0.5 (0.5)				12.5 (23.0)	1.0 (0.5)		
20-25 cm	15.0 (17.0)			1.0 (0.5)	2.5 (4.5)			0.5 (0.5)		0.5 (0.5)		22.0 (22.5)			
30-35 cm	3.5 (5.5)			(0.5)	1.0 (1.0)				(1.0)			38.0 (44.5)			1.5
40-45 cm	5.5 (6.5)		0.5 (0.5)								0.5 (0.5)	46.0 (52.5)			
50-55 cm	2.0 (2.0)				(1.0)				0.5 (0.5)			40.0 (40.5)			4.0 (4.5)
60-65 cm	3.5 (4.5)			0.5 (1.5)	5.0 (7.0)			0.5 (1.0)	0.5 (0.5)		1.0 (1.0)	24.5 (37.0)		(1.5)	3.0 (3.0)

Sample No.	Rubiaceae	Onagraceae	*Cardamine*	*Hibbertia*	*Orites* (?)	Proteaceae	*Goodenia*	*Claytonia*	Compositae	Umbelliferae	*Plantago*	Cheno-ams	*Richea* (?)	*Oxylobium*	*Dodonaea*
Surface									23.0						0.5
Pond							0.5 (0.5)		16.0 (34.5)	2.0 (3.0)		(1.0)			
10-15 cm									12.0 (24.0)	2.0 (2.5)	0.5 (0.5)	13.0 (20.0)			
20-25 cm		(0.5)							8.0 (15.0)		0.5 (0.5)	19.5 (33.0)			
30-35 cm				0.5 (0.5)					7.5 (10.0)	1.0 (1.0)		22.0 (31.0)			
40-45 cm				0.5 (0.5)					13.5 (18.5)			10.0 (11.5)			
50-55 cm									9.0 (9.0)		0.5 (0.5)	31.0 (36.0)			
60-65 cm		0.5 (0.5)		(0.5)			(1.0)		12.0 (17.0)	0.5	4.0 (4.0)	11.0 (12.5)			

Sample No.	Convolvulaceae	*Myriophyllum*	*Haloragis*	*Drimys* (?)	Cyperaceae	*Triglochin*	*Potamogeton*	Liliaceae	Unknowns
Surface					1.5				4.5
Pond		26.0			19.0	2.0			2.0 (2.5)
10-15 cm		13.5			18.0		4.0	1.5	7.5 (9.0)
20-25 cm		13.5			11.0			0.5	4.5 (5.5)
30-35 cm		14.0			6.0				5.0 (5.0)
40-45 cm		7.0			8.0			1.0	7.5 (9.5)
50-55 cm		2.5			3.5		0.5	1.0	5.5 (6.0)
60-65 cm		8.5			9.5		5.5	3.0	7.0 (7.5)

Sample No.	*Eucalyptus* (*Myrtaceae*)	*Acacia*	*Banksia*	*Casuarina*	*Phyllocladus*	*Pinus*	*Picea*	*Pherosphaera*	Cupressaceae	*Nothofagus*	*Podocarpus*	Gramineae	*Pomaderris*	*Bursaria*	Caryophyllaceae
70-75 cm	3.5 (4.0)			1.5 (2.5)	5.5 (5.5)			0.5 (1.0)		0.5 (0.5)	0.5 (1.0)	32.5 (42.0)		0.5 (1.0)	
80-85 cm	1.0 (4.0)			(7.5)	(10.0)			(4.0)			0.5 (1.0)	3.0 (28.0)			
90-95 cm	3.5 (10.0)			(5.0)	0.5 (5.5)			(2.5)			(1.5)	5.0 (29.0)			
100-105 cm	1.5 (6.0)			(3.0)	0.5 (3.0)				1.0 (1.5)		0.5 (2.0)	5.0 (16.5)			
110-115 cm	1.0 (11.0)			1.0 (12.0)	(17.0)			(6.5)	(1.0)		(0.5)	1.0 (13.5)			
120-125 cm	0.5 (6.5)			0.5 (7.5)	0.5 (7.5)			(1.0)	(2.0)		(1.0)	1.0 (9.0)			
130-135 cm	(7.5)			(7.5)	1.0 (14.0)			1.0 (3.5)			0.5 (0.5)	4.0 (16.0)			0.5 (0.5)
140-145 cm	0.5 (11.0)			0.5 (7.5)	1.5 (23.0)			0.5 (4.0)	(2.0)	(3.0)		2.0 (10.0)			(2.0)

Sample No.	Rubiaceae	Onagraceae	*Cardamine*	*Hibbertia*	*Orites* (?)	Proteaceae	*Goodenia*	*Claytonia*	Compositae	Umbelliferae	*Plantago*	Cheno-ams	*Richea* (?)	*Oxylobium*
70-75 cm				(1.5) (1.5)					7.0 (14.0)	1.0 (1.0)	2.0 (2.5)	8.5 (11.5)	1.0 (1.0)	0.5 (0.5)
80-85 cm	(1.0)			(0.5)					1.5 (19.0)	(1.0)	0.5 (1.0)	0.5 (15.0)		
90-95 cm									3.5 (24.5)	1.5 (1.5)		2.0 (12.0)		
100-105 cm		(0.5)	(0.5)						0.5 (20.0)	(1.5)		3.5 (39.0)		
110-115 cm			0.5 (0.5)		(0.5)				1.0 (24.5)	(1.0)		1.0 (5.0)		
120-125 cm				(0.5)					3.0 (20.5)	(0.5)		2.5 (39.0)		
130-135 cm									3.0 (16.5)	(2.5)		(26.0)		
140-145 cm						(1.0)			1.0 (18.0)	1.5 (2.0)		1.0 (9.5)		

Sample No.	Convolvulaceae	*Myriophyllum*	*Haloragis*	*Drimys*	Cyperaceae	*Triglochin*	*Potamogeton*	Lilliaceae	Unknowns
70-75 cm	(0.5)	17.5	0.5		5.5		1.0	1.0	8.0 (10.0)
80-85 cm		91.0			1.0				1.0 (8.0)
90-95 cm		76.5			2.0		1.0		4.5 (8.5)
100-105 cm		83.0				2.5			2.0 (6.5)
110-115 cm		88.0			4.0	0.5	1.0		1.0 (7.0)
120-125 cm		89.0			1.0		1.0		1.0 (5.0)
130-135 cm		76.5			5.5	4.5	2.5		1.0 (5.5)
140-145 cm		80.0		0.5	5.0	1.0	2.0	1.0	2.0 (7.0)

Sample No.	*Eucalyptus* (*Myrtaceae*)	*Acacia*	*Banksia*	*Casuarina*	*Phyllocladus*	*Pinus*	*Picea*	*Pherosphaera*	Cupressaceae	*Nothofagus*	*Podocarpus*	Gramineae	*Pomaderris*	*Bursaria*	Caryophyllaceae
150-155 cm	0.5 (16.5)			(8.5)	(9.0)			0.5 (3.0)	(1.0)			2.0 (5.5)			
160-165 cm	0.5 (8.5)			1.0 (6.5)	2.5 (9.0)			(1.5)				1.0 (14.5)			0.5 (1.0)
170-175 cm	2.5 (14.0)			0.5 (8.5)	1.0 (5.0)							1.5 (12.5)			

Sample No.	Rubiaceae	*Onagraceae*	*Cardamine*	*Hibbertia*	*Orites (?)*	Proteaceae	*Goodenia*	*Claytonia*	Compositae	Umbelliferae	*Plantago*	Cheno-ams	*Richea (?)*	*Oxylobium*	*Villarsia*
150-155 cm							(0.5)		(31.0)	(1.0)		2.5 (18.5)			
160-165 cm								(1.0)	3.5 (19.5)	(2.0)		1.0 (28.0)			
170-175 cm							(0.5)		3.5 (23.5)	0.5 (2.0)		2.0 (26.5)			0.5

Sample No.	Convolvulaceae	*Myriophyllum*	*Haloragis*	*Drimys*	Cyperaceae	*Triglochin*	*Potamogeton*	Liliacea	Unknowns
150-155 cm		92.5			1.0			1.0	(5.5)
160-165 cm		85.0			4.0		0.5	0.5	(8.5)
170-175 cm		83.0			2.0			1.0	2.0 (7.5)

REFERENCES CITED

ADAM, D.P., 1967. Late Pleistocene and Recent palynology in the Central Sierra Nevada, California. In E.J. Cushing and H.E. Wright, Jr. (eds.), *Quaternary Paleoecology*. Yale Univ. Press, New Haven, pp. 275-301.

AHMAD, N., BARTLETT, A., and GREEN, D.H., 1959. The glaciation of the King Valley, western Tasmania. *Proc. Roy. Soc. Tasm.*, 93: 11-16.

ANTEVS, E., 1948. Climatic changes and pre-white man. *Univ. Utah Bull.*, 38: 168-93.

AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE, 1961. Code of Stratigraphic Nomenclature. *Amer. Assoc. Petr. Geol. Bull.*, 45: 645-65.

ATLAS OF TASMANIA, 1965. J.L. Davies (ed.), Mercury Press, Hobart, 128 pp.

BANKS, M.R., 1965. Geology and mineral deposits. In J.L. Davies (ed.), *Atlas of Tasmania*. Mercury Press, Hobart, pp. 12-17.

BARENDSEN, G.W., DEEVEY, E.S., and GRALENSKI, L.J., 1957. Yale Natural Radiocarbon Measurements III, *Science*, 126: 908-19.

BETTENAY, E., 1962. The salt lake systems and their associated aeolian features in the semi-arid regions of Western Australia. *J. Soil Sci.*, 13: 10-17.

BIRDSELL, J.B., 1957. Some population problems involving Pleistocene Man. In *Population studies: animal ecology and demography. Cold Spring Harbor Symposia in Quantitative Biology*, 22: 47-69.

BIRKELAND, P.W., 1967. Correlation of soils of stratigraphic importance in Western Nevada and California, and the relative rates of profile development. In R.B. Morrison and H.E. Wright, Jr. (eds.), *Quaternary Soils*. Desert Res. Inst., Univ. Nevada, Reno, pp. 71-92.

BOWDEN, A.R., 1974. *The Glacial Geomorphology of the Tyndall Mountains, Western Tasmania.* Unpublished Honors thesis, The University of Tasmania, Hobart, 80 p.

BOWDLER, S., 1974a. Pleistocene date for man in Tasmania. *Nature*, 252: 697-8.

BOWDLER, S., 1974b. An account of an archeological reconnaissance of Hunter's Isles, northwest Tasmania, 1973/74. *Rec. Q. Vict. Mus., Launceston*, No. 54, 22 pg.

BOWLER, J.M., 1967. Quaternary chronology of the Goulburn Valley sediments and their correlation in southeastern Australia. *J. Geol. Soc. Aust.*, 14: 287-92.

BOWLER, J.M. 1968. Lunette. *Aust. Geogr.*, 10: 402-4.

BOWLER, J.M., 1971. Pleistocene salinities and climatic change: evidence from lakes and lunettes in southeastern Australia. In D.J. Mulvaney and J. Golson (eds.), *Aboriginal Man and Environment in Australia.* ANU Press, Canberra, pp. 47-65.

BOWLER, J.M., 1973a. Clay dunes: their occurrence, formation, and environmental significance. *Earth-Sci. Rev.*, 9: 315-38.

BOWLER, J.M., 1973b. Late Pleistocene environments in the Southern Hemisphere: evidence from playa lakes in southern Australia. (abs.), *IX Cong. INQUA, New Zealand,* pp. 37-8.

BOWLER, J.M., and HAMADA, T., 1971. Late Quaternary stratigraphy and radiocarbon chronology of water level fluctuations in Lake Keilambete, Victoria. *Nature,* 232: 331-2.

BOWLER, J.M., and HARFORD, L.B., 1966. Quaternary tectonics and the evolution of the Riverina Plain near Echuca, Victoria. *J. Geol. Soc. Aust.*, 13: 339-54.

BOWLER, J.M., JONES, R., ALLEN, H., and THORNE, A.G., 1970. Pleistocene human remains from Australia: a living site and human cremation from Lake Mungo, western New South Wales. *World Archaeol.*, 2: 39-60.

BREWER, R., 1964. *Fabric and Mineral Analysis of Soils.* John Wiley and Sons, New York, 470 p.

BREWER, R., 1972. Use of macro- and micromorphological data in soil stratigraphy to elucidate surficial geology and soil genesis. *J. Geol. Soc. Aust.*, 19: 331-34.

BROWN, G., 1961. *The X-ray Identification and Crystal Structures of Clay Minerals.* The Mineralogical Society, London, 544 p.

BROWNE, W.R., 1945. An attempted Post Tertiary chronology for Australia. *Proc. Linn. Soc. N.S.W.*, 70: xxiv

BUTLER, B.E., 1950. A theory of prior streams as a causal factor in the distribution of soils in the Riverina Plain of southeastern Australia. *Aust. J. Agr. Res.*, 1: 231-52.

BUTLER, B.E., 1956. Parna, an aeolian clay. *Aust. J. Sci.,* 18: 145-51.

BUTLER, B.E., 1958. Depositional systems of the Rivernia Plain in relation to soils. *CSIRO (Aust.) Soil Publ.,* 10, 35 p.

BUTLER, B.E., 1959. Periodic phenonmena in landscapes as a basis for soil studies. *CSIRO (Aust.), Soil Publ.,* 14, 20 p.

BRYAN, K., and ALBRITTON, C.C., 1943. Soil phenomena as evidence of climatic changes. *Amer. J. Sci.,* 241: 470-82.

BUTZER, K.W., 1963. Climatic-geomorphologic interpretation of Pleistocene sediments in the Eurafrican subtropics. *Viking Fund Publ. Anthropol.,* 36: 1-27.

BUTZER, K.W., 1964. *Environment and Archeology: An Introduction to Pleistocene Geography.* Methuen and Co., London, 524 p.

CAMPBELL, E.M., 1968. Lunettes in southern South Australia. *Trans. Roy. Soc. S.A.,* 92: 85-109.

CAREY, S.W., 1947. Geology of the Launceston district. *Rec. Q. Vict. Mus., Launceston,* 2: 31-46.

CHURCHILL, D.M., 1968. The distribution and prehistory of *Eucalyptus diversicolor* F. Muell., *E. marginata* Donn EX SM., and *E. calophylla* R.BR. in relation to rainfall. *Aust. J. Bot.,* 16: 125-51.

COMMONWEALTH BUREAU OF METEOROLOGY, 1972. *Climatic Survey, Midland Region 4, Tasmania.* Aust. Govt. Publ. Service, Canberra, 194 p.

COOK, S.F., 1963. Erosion morphology and occupation history in Western Mexico. *Anthropological Records.* 17: 3, Univ. Calif. Press, Berkley and Los Angeles, 334 p.

COOPER, W.S., 1935. The history of the upper Mississippi River in the late Wisconsin and postglacial time. *Minn. Geol. Surv. Bull.,* 26, 116 p.

CORBETT, J.R., 1969. *The Living Soil: The Processes of Soil Formation.* Martindale Press, West Como, 326 p.

COSTIN, A.B., 1971 Vegetation, soils, and climate in late Quaternary southeastern Australia. In D.J. Mulvaney and J. Golson (eds.), *Aboriginal Man and Environment in Australia.* ANU Press, Canberra, pp. 27-37.

COTTON, C.A., 1963. Did the Murrumbidgee aggradations take place in glacial ages? *Aust. J. Sci.,* 26: 54-5.

COWIE, J.D., 1959. Reconnaissance soil map of Tasmania. Sheet 68 - Oatlands. *CSIRO (Aust.) Div. Soil, Div. Rept.* 4/59, 8 p.

CROCKER, R.L., 1946. Post-Miocene climate and geologic history and its significance in the genesis of the major soil types of South Australia. *CSIRO Bull.,* 193.

CROCKER, R.L. and COTTON, B.C., 1946. Some raised beaches in the lower southeast of South Australia. *Trans. Roy. Soc. S.A.,* 70: 64-82.

CROCKER, R.L. and WOOD, J.G., 1947. Some historical influences on the development of the South Australian vegetation communities and their bearing on concepts and classification in ecology. *Trans. Roy. Soc. S.A.,* 71: 91-136

CRUICKSHANK, J.G., and HEIDENREICH, C.E., 1969. Pedological investigations at the Huron Indian village of Cahiague. *Can. Geogr.* 8: 34-36.

CURRY, D.T., 1964. The former extent of Lake Corangamite. *Proc. Roy. Soc. Vict.,* 77: 377-86.

CURTIS, W.M., 1967. *The Student's Flora of Tasmania.* D.E. Wilkinson, Govt. Printer, Hobart, 655 p.

DAVIES, J.L., 1959a. High level erosion surfaces and landscape development in Tasmania. *Aust. Geogr.* 7: 193-203.

DAVIES, J.L., 1959b. Sea level change and shoreline development in southeastern Tasmania. *Proc. Roy. Soc. Tasm.,* 93: 83-95.

DAVIES, J.L., 1965. Landforms. In J.L. Davies (ed.), *Atlas of Tasmania.* Mercury Press, Hobart, pp. 19-22.

DAVIES, J.L., 1967. Tasmanian landforms and Quaternary climates. In J.N. Jennings and J.A. Mabbutt, (eds.) *Landform Studies from Australia and New Guinea.* ANU Press, Canberra, pp. 1-25.

DAVIES, J.L., 1974. Geomorphology and Quaternary environments. In W.D. Williams (ed.), *Biogeography and Ecology of Tasmania.* Dr. W. Junk b.v., Publ., The Hague, pp. 17-27.

DAVIS, M.B., 1969. Palynology and environmental history during the Quaternary Period, *Amer. Scien.,* 57: 317-32.

DERBYSHIRE, E., 1971. A synoptic approach to the atmospheric circulation of the last glacial maximum in southeastern Australia. *Paleogeogrm., Paleoclim., Paleoecol.*, 10: 103-24.

DERBYSHIRE, E., 1972. Pleistocene glaciation of Tasmania: review and speculations. *Aust. Geogr. Stud.*, 10: 79-94.

DERBYSHIRE, E., 1973. Periglacial phenomena in Tasmania. *Biul. Peryglac.*, 22: 131-47.

DIMMOCK, G.M., 1957. Reconnaissance soil map of Tasmania, Sheet 75 - Brighton. *CSIRO (Aust.) Div. Soil*, Div. Rept., 2/57, 6 p.

DODSON, J.R., 1974. Vegetation history and water fluctuations at Lake Leake, Southeastern South Australia. I. 10,000 BP to present. *Aust. J. Bot.*, 22: 719-41.

DODSON, J.R., 1975. Vegetation history and water fluctuations at Lake Leake, Southeastern South Australia. II. *Aust. J. Bot.*, 23: 815-31.

DURY, G.H., 1960. Misfit streams, problems in interpretation, discharge and distribution. *Geog. Rev.*, 50: 219-42.

DURY, G.H., 1967. Climatic change as a geographical backdrop. *Aust. Geogr.*, 10: 231-42.

DURY, G.H., 1968. An introduction to the geomorphology of Australia. In G.H. Dury and M.I. Logan (eds.), *Studies in Australian Geography*, Heineman Educational Australia, Melbourne, pp. 1-36.

DURY, G.H., 1973. Paleohydrologic implications of some pluvial lakes in northwestern New South Wales, Australia. *Bull. Geol. Soc. Amer.*, 84: 3663-76.

ERDTMAN, G., 1943. *An Introduction to Pollen Analysis.* Ronald Press. New York. 239 pp.

ERDTMAN, G., 1957. *Pollen Morphology and Plant Taxonomy.* Almqvist and Wiksell, Stockholm, 539 p.

FAEGRI, K., and IVERSEN, J., 1964. *Textbook of Modern Pollen Analysis.* Munksgaard, Copenhagen, Hafner Publ. Co., New York, 237 p.

FAIRBRIDGE, R.W., 1961. Eustatic changes in sea level. In L.H. Ahrens *et al.*, (eds.), *Physics and Chemistry of the Earth.* 4: 99-185.

FITZPATRICK, E.A., 1971. *Pedology: A systematic approach to soil science.* Oliver and Boyd, Edinburgh, 306 p.

FLINT, R.F., 1947. *Glacial Geology and the Pleistocene Epoch.* John Wiley, New York, 589 p.

FLINT, R.F., 1971. *Glacial and Quaternary Geology.* John Wiley, New York. 892 p.

FOLK, R.L., 1965. *Petrology of Sedimentary Rocks.* Hemphill's, Austin, Texas, 159 p.

FRYE, J.C., WILLMAN, H.B., and GLASS, H.D., 1960. Gumbotil, accretiongley, and the weathering profile. *Ill. Geol. Surv. Circ.* 295, 39 p.

GALLOWAY, R.W., 1965a. Late Quaternary climates in Australia. *J. Geol.* 73: 603-618.

GALLOWAY, R.W., 1965b. A note on world precipitation during the last glaciation. *Eiszeit. and Gegenwart,* 16: 76-7.

GALLOWAY, R.W., 1967. Dating of shore features at Lake George, New South Wales. *Aust. J. Sci.,* 29: 477.

GALLOWAY, R.W., 1971. Evidence for Late Quaternary climates. In D.J. Mulvaney and J. Golson (eds.), *Aboriginal Man and Environment in Australia.* ANU Press, Canberra, pp. 14-25.

GALLUS, A., 1971. The artifact. In *Newsletter of the Archaeol. Soc. Vict.,* Melbourne, 24, 1.

GENTILLI, J., 1961. Quaternary climates of the Australian Region. *Ann. N.Y. Acad. Sci.,* 95: 465-501.

GEOL. SURV. TASM., 1972. Hobart Geological Map, Sheet 82. Tasm. Dept. Mines, Hobart.

GILBERT, J.M., 1958. Forest succession in the Florentine Valley, Tasmania. *Proc. Roy. Soc. Tasm.,* 9: 129-51.

GILL, E.D., 1955. The Australian Arid Period. *Aust. J. Sci.,* 17: 204-6.

GILL, E.D., 1956. Radiocarbon dating of glacial varves in Tasmania. *Aust. J. Sci.,* 19: 80.

GILL, E.D., and BANKS, M.R., 1956. Cainozoic history of Mowbray Swamp and other areas of northwestern Tasmania. *Rec. Q. Vict. Mus., Launceston,* N.S. 6, 36 p.

GOEDE, A., 1965. The geomorphology of the Buckland basin. *Proc. R. Soc. Tasm.*, 99: 133-54.

GOEDE, A., 1973. Floodplain stratigraphy of the Tea Tree Rivulet. *Aust. Geogr. Stud.*, 11: 28-39.

GOLSON, J., 1972. The remarkable history of Indo-Pacific Man: missing chapters from every world prehistory. *Search*, 3: 13-21.

HALLSWORTH, E.G., ROBERTSON, G.K., and GIBBONS, F.R., 1955. Studies in pedogenesis in New South Wales. VII. The gilgai soils. *J. Soil Sci.*, 6: 1-31.

HANSEN, H.P., 1949. Pollen content of moss polsters in relation to forest composition. *Amer. Midl. Nat.*, 42: 473-79.

HARTSHORNE, R., 1959. Perspective on the nature of Geography. *Assoc. Amer. Geogr., Monograph Series, No. 1,* Rand McNally, Chicago, 200 p.

HENDY, C., 1969. Isotope studies of speleothems. *N.Z. Speleol. Bull.*, No. 71, 4: 306-19.

HEVLY, R.H., MEHRINGER, P.J., and YOKUM, H.G., 1965. Modern pollen rain in the Sonoran Desert. *J. Ariz. Acad. Sci.*, 3: 123-35.

HIATT, B., 1968. The food quest and economy of the Tasmanian Aborigines. *Oceania.* 38: 190-219.

HILLS, C.L., and CAREY, S.W., 1949. Geology and mineral industry. In *Handbook for Tasmania.* Aust. Assoc. Adv. Sci., Hobart, 73 p.

HILLS, E.S., 1939. The physiography of North-western Victoria. *Proc. Roy. Soc. Vict.*, 51: 297-323.

HILLS, E.S., 1940. The Lunette; a new landform of aeolian origin. *Aust. Geogr.*, 10: 408-9.

HORIE, S., 1965. Late Pleistocene climatic changes inferred from the stratigraphic sequences of Japanese lake sediments. In R.B. Morrison and H.E. Wright, Jr. (eds.). *Means of Correlation of Quaternary Successions.* Univ. of Utah Press, Salt Lake City, pp. 311-24.

HUDSON, N.W., and JACKSON, D.C., 1959. Results achieved in the measurement of erosion and runoff in Southern Rhodesia. *3rd, Inter-African Soil Conference, Dalaba,* Paper No. 63.

IVES, David, 1973. Nature and distribution of loess in Canterbury, New Zealand. *N.Z. J. Geol. and Geophys.* 16: 587-610.

JACKSON, M.L., 1956. *Soil Chemical Analysis - Advanced Course.* (Fourth printing, 1968), University of Wisconsin, Madison, 894 p.

JACKSON, W.D., 1965. Vegetation. In J.L. Davies (ed.), *Atlas of Tasmania.* Mercury Press, Hobart, pp. 30-5.

JACKSON, W.D., 1968. Fire, air, water, and earth - an elemental ecology of Tasmania. *Proc. Ecol. Soc. Aust.,* 3: 9-16.

JACKSON, W.D., 1973. Vegetation of the Central Plateau. In M.R. Banks (ed.), *The Lake Country of Tasmania.* Roy. Soc. Tasm., Hobart, pp. 61-85.

JACKSON, W.D., 1974. Conservation in Tasmania. In R.L. Specht, E.M. Roe, and V.H. Boughton (eds.), *Conservation of Major Plant Communities in Australia and Papua New Guinea.* Aust. J. Bot. Suppl. Series, 7: 322-448.

JENNINGS, J.N., 1959a. The submarine topography of Bass Strait. *Proc. Roy. Soc. Vict.,* 71: 49-72.

JENNINGS, J.N., 1959b. The coastal geomorphology of King Island, Bass Strait, in relation to changes in the relative level of land and sea. *Rec. Q. Vic., Mus. Launceston,* N.S. 11, 39 pp.

JENNINGS, J.N., 1967. Cliff-top dunes. *Aust. Geog. Stud.,* 5: 40-9.

JENNINGS, J.N., 1971. Sea level changes and land links. In D.J. Mulvaney and J. Golson (eds.), *Aboriginal Man and Environment in Australia.* ANU Press, Canberra, pp. 1-13.

JONES, M.D., and NEWELL, L.C., 1948. Size, variability and identification of grass pollen. *J. Amer. Soc. Agron.,* 40: 136-43.

JONES, R., 1966. A speculative archaeological sequence for northwest Tasmania. *Rec. Q. Vic. Mus. Launceston,* No. 25, 12 p.

JONES, R., 1967. Middens and Man in Tasmania. *Aust. Nat. Hist. Mag.,* (Sept., 1967), pp. 359-64.

JONES, R., 1968. The geographical background to the arrival of man in Australia and Tasmania. *Arch. and Phys. Anthr. in Oceania,* 3: 186-215.

JONES, R., 1971. The demography of hunters and gather-farmers in Tasmania. In D.J. Mulvaney and J. Golson (eds.), *Aboriginal Man and Environment in Australia.* ANU Press, Canberra, pp. 271-87.

JONES, R., 1973. Emerging picture of Pleistocene Australians. *Nature*, 246: 278-281.

KAPP, R.O., 1969. *Pollen and Spores*. Wm. C. Brown Co., Dubuque, Iowa, 249 p.

KING, J.E., and SIGLEO, W.R., 1973. Modern pollen in the Grand Canyon, Arizona. *Geosci. and Man*, 3: 73-81.

KIRKBY, M.J., 1969. Erosion by water on hillslopes. In R.J. Chorley (ed.), *Water, Earth and Man: A synthesis of hydrology, geomorphology and socio-economic geography*, Methuen and Co., London, pp. 229-38.

KROEBER, A.L., 1939. Cultural and Natural areas in native North America. *Univ. of California Publ. in Amer. Arch. and Ethnol.*, 38, Berkeley.

KRUMBEIN, W.C., and PETTIJOHN, F.J., 1938. *Manual of Sedimentary Petrography*. Appleton-Century-Crofts, Inc., New York, 549 p.

KUBIENA, W.L., 1953. *The Soils of Europe*. Thomas Murby and Co., London, 318 p.

LANGFORD, J., 1965. Weather and Climate. In J.L. Davies (ed.), *Atlas of Tasmania*. Mercury Press, Hobart, pp. 2-11.

LANGFORD-SMITH, T., 1959. Deposition on the Riverina Plain of southeastern Australia. *Aust. J. Sci.*, 22: 73-4.

LANGFORD-SMITH, T., 1960. The dead river systems of the Murrumbidgee. *Geog. Rev.*, 50: 368-89.

LANGFORD-SMITH, T., 1962. Riverina Plains geochronology. *Aust. J. Sci.*, 25: 96-7.

LEAMY, M.L., 1961. Reconnaissance soil Map of Tasmania. Sheet 61 - Interlaken (Eastern Half). *CSIRO, (Aust.) Div. Soils*, Div. Rept. 6/61, 9 p.

LEOPOLD, L.B., WOLMAN, M.G., and MILLER, J.P., 1964. *Fluvial Processes in Geomorphology*. Freeman and Co., San Francisco, 521 p.

LEWIS, A.N., 1935. Correlation of Tasmania Pleistocene raised beaches and river terraces in unglaciated areas. *Proc. Roy. Soc. Tasm.*, (1934), pp. 75-86.

LEWIS, A.N., 1945. Time scales in the development of Tasmania physiography. *Proc. Roy. Soc. Tasm.*, (1944), pp. 19-39.

LOUGHAN, F.C., 1969. *Chemical Weathering of the Silicate Minerals.* Elsevier Publ. Co., New York, 154 p.

LOURANDOS, H., 1970. *Coast and Hinterland: the archaeological sites of eastern Tasmania.* Unpublished M.A. thesis, ANU, Canberra, 161 p.

LOVEDAY, J., 1955. Reconnaissance soil map of Tasmania, Sheet 82 - Hobart. *CSIRO (Aust.) Div. Soil,* Div. Rept., 13/55, 7 p.

MACPHAIL, M.K., and PETERSON, J.A., 1975. New deglaciation dates from Tasmania. *Search,* 6: 127-30.

MARTIN, D., 1940. The vegetation of Mt. Wellington, Tasmania. *Proc. Roy. Soc. Tasm.,* 39: 97-124.

MARTIN, H.A., 1973. Palynology and historical ecology of some cave excavations in the Australian Nullarbor. *Aust. J. Bot.,* 21: 283-316.

MARTIN, P.S., 1963. *The Last 10,000 Years, a Fossil Pollen Record of the American Southwest.* Univ. of Arizona Press, Tucson, 87 p.

MARTIN, P.S., 1966. Africa and Pleistocene overkill. *Nature,* 212: 339-42.

MARTIN, P.S., SCHOENWETTER, J., and ARMS, B.C., 1961. *Southwestern Palynology and Pre-history.* Geochronology Laboratories, Univ of Arizona, 118 pp. (Mimeographed)

McDOUGALL, I., 1959. The Brighton basalts, Tasmania. *Proc. Roy. Soc. Tasm.,* 93: 17-28.

MEHRINGER, P.J., 1967. Pollen analysis of the Tule Springs Area, Nevada. In H. Wormington and D. Ellis (eds.), *Pleistocene Studies in Southern Nevada.* Nevada State Museum, Anthropological Papers, No. 13, Carson City, pp. 130-200.

MEHRINGER, P.J., and HAYNES, C.V., 1965. The pollen evidence for the environment of early Man and extinct mammals at the Lehner Mammoth site, southeastern Arizona. *Amer. Antiq.,* 31: 17-23.

MERRILEES, D., 1967. Man the destroyer: late Quaternary changes in the Australian marsupial fauna. *J. Roy. Soc. W. Aust.,* 51: 1-24.

MILLIMAN, J.D., and EMERY, K.O., 1968. Sea level during the past 35,000 years. *Science,* 162: 1121-23.

MORRISON, R.B., 1965. Quaternary geology of the Great Basin. In H.E. Wright, Jr., and D.G. Frey (eds.), *Quaternary of the United States.* Princeton Univ. Press, Princeton, N.J., pp. 265-85.

MORRISON, R.B., 1967. Principles of Quaternary soil stratigraphy. In R.B. Morrison and H.E. Wright, Jr. (eds.), *Quaternary Soils*. Desert Res. Inst., Univ. of Nevada, Reno, pp. 1-70.

MULCAHY, M.J., and CHURCHWARD, H.M., 1973. Quaternary environments and soils in Australia. *Soil sci.*, 116: 156-69.

MULVANEY, D.J., (1968). *The Prehistory of Australia.* Thames and Hudson, London, 276 p.

MUNSELL SOIL COLOR CHARTS, 1954. Munsell Color Co., Baltimore.

NICOLLS, K.D., 1958a. Reconnaissance soils map of Tasmania. Sheet 47, Longford. *CSIRO (Aust.) Div. Soils, Div. Rept.*, 14/57, 16 p.

NICOLLS, K.D., 1958b. Aeolian deposits in river valleys in Tasmania. *Aust. J. Sci.*, 21: 50-1.

NICOLLS, K.D., 1960. Erosion surfaces, river terraces, and river capture in the Launceston Tertiary Basin. *Proc. Roy. Soc. Tasm.*, 94: 1-12.

NICOLLS, K.D., and DIMMOCK, G.M., 1965. Soils. In J.L. Davies (ed.), *Atlas of Tasmania.* Mercury Press, Hobart, pp. 27-9.

NYE, P.B., 1921. The underground water resources of the Midlands. *Underg. Wat. Resour. Pap. Tasm.*, 1, pp. 1-139.

ODUM, E.P., 1959. *Fundamentals of Ecology.* W.B. Sanders Co., Philadelphia, 546 p.

OERTEL, A.C., 1968. Some observations incompatible with clay illuviation. *Trans. 9th Inter. Con. Soil. Sci.*, Vol. IV, pp. 481-88.

OLSON, J.S., 1968. Eolian transport. In: Fairbridge, R.W., (ed.), *Encyclopedia of Geomorphology*. Dowden, Hutchinson and Ross, Inc., Stroudsburg, PA., pp 309-312.

PATERSON, S.J., DUIGAN, S.L., and JOPLIN, G.A., 1967. Notes on Pleistocene deposits at Lemonthyme Creek in the Forth Valley. *Proc. Roy. Soc. Tasm.*, 101: 221-25.

PELS, S., 1971. River systems and climatic changes in southeastern Australia. In D.J. Mulvaney and J. Golson (eds.), *Aboriginal Man and Environment in Australia.* ANU Press, Canberra, pp. 38-46.

PETERSON, J.A., 1968. Cirque morphology and Pleistocene ice formation conditions in southeastern Australia. *Aust. Geogr. Stud.*, 6: 67-83.

PIKE, K.M., 1956. Pollen morphology of Myrtaceae from the southwest Pacific area. *Aust., J. Bot.*, 4: 13-53.

PRICE, W.A., 1963. Physicohemical and environmental factors in clay dune genesis. *J. Sed. Petrol.*, 33: 766-78.

PRICE, W.A., and KORNICKER, L.S., 1961. Marine and lagoonal deposits in clay dunes, Gulf Coast, Texas. *J. Sed. Petrol.*, 31: 245-55.

PRYOR, L.D., and BODEN, R.W., 1862. Blowflies as pollinators in producing Eucalyptus seed. *Aust. J. Sci.*, 24: 326.

PTOMLEY, N.L.B. (ed.), 1966. *Friendly Mission: The Tasmanian Journals of George Augustus Robinson, 1829-1834.* Tasm. Hist. Res. Assoc., Hobart, 1074 pp.

REBER, G., 1965. Aboriginal carbon dates from Tasmania. *Mankind,* 6: 264-8.

RICHMOND, G.M., 1962. Quaternary stratigraphy of the La Sal Mountains, Utah. *U.S. Geol. Surv. Prof. Pap.*, 324, 135 p.

RUSSELL, E.W., 1961. *Soil Conditions and Plant Growth.* Longmans, Green and Co., London, 688 p.

SAUER, C.O., 1925. The morphology of landscape. *Univ. Calif. Publ. in Geography,* 2: 19-53.

SCHUMM, S.A., 1968. River adjustment to altered hydrologic regimen - Murrumbidgee River and paleochannels, Australia. *4.S. Geol. Surv. Prof. Pap.*, 598, 65 p.

SEWARD-THOMPSON, B.L., and Hails, J.R., 1973. An appraisal of the computation of statistical parameters in grain size analysis. *Sediment.*, 20: 161-9.

SHEPARD, F.P., 1961. Sea level rise during the past 20,000 years. *Z. fur Geomorphol. suppl.*, 30-5.

SIGLEO, W.R., and COLHOUN, E.A., 1975. Glacial Man in southeastern Tasmania: evidence from the Old Beach site. *Search,* 6: 300-2.

SOIL SURVEY STAFF, 1962. Identification and nomenclature of soil horizons. *Soil Survey Manual, suppl. to Agricultural Handbook, No. 18,* replacing pp. 173-188.

SPECK, N.H., 1953. Atmospheric pollen in the city of Perth and environs. *Proc. Roy, Soc. W. Aust.*, 119-27.

SPRY, A., and BANKS, M.R., (eds.), 1962. *The Geology of Tasmania.* J. Geol. Soc. Aust., Vol. 9, Part 2, The Griffin Press, Adelaide, 262 p.

STACE, H.C.T., HUBBLE, G.D., BREWER, R., NORTHCOTE, K.H., SLEEMAN, J.R., MULCAHY, M.J., and HALLSWORTH, E.G., 1968. *A Handbook of Australian Soils.* Rellim Tech. Publs. South Australia, 435 p.

STEPHENS, C.G., BALDWIN, J.G., and HOSKING, J.S., 1942. The soils of the parishes of Longford, Cressy and Lawrence, County Westmorland, Tasmania. *CSIRO Bull. 150* Melbourne, 34 p.

STEPHENS, C.G., and CROCKER, R.L., 1946. Composition and genesis of lunettes. *Trans. Roy. Soc. S. Aust.*, 70: 302-12.

TASMANIAN YEAR BOOK, 1974. *The climate of Tasmania.* Aust. Bureau of Statistics, Govt. Printing Office, Hobart, pp. 40-51.

THORNE, A.G., 1971a. The racial affinities and origins of the Australian Aboriginals. In D.J. Mulvaney and J. Golson (eds.), *Aboriginal Man and Environment in Australia.* ANU Press, Canberra, pp. 316-26.

THORNE, A.G., 1971b. Mungo and Kow Swamp: morphological variation in Pleistocene Australians. *Mankind,* 8: 85-9.

THORNE, A.G., and MACUMBER, P.G., 1972. Discoveries of late Pleistocene Man at Kow Swamp, Australia. *Nature,* 238: 316-19.

TOWNROW, J.E.S., 1969. A species list of and key to the grasses in Tasmania. *Proc. Roy. Soc. Tasm.,* 103: 69-96.

VON STIEGLITZ, K.R., 1960. *A History of Oatlands and Jericho.* Telegraph Printery Co., Launceston, 92 p.

WASHBURN, A.L., 1973. *Periglacial Processes and Environments.* Edward Arnold Publ., London, 320 p.

ZEUNER, F.E., 1959. *The Pleistocene Period. Its climate, chronology and faunal successions.* 2nd ed., Hutchinson, London, 447 p.